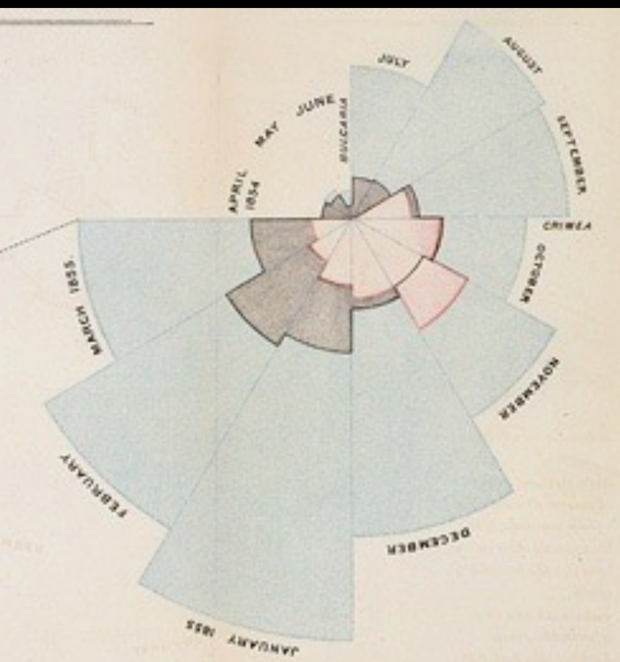
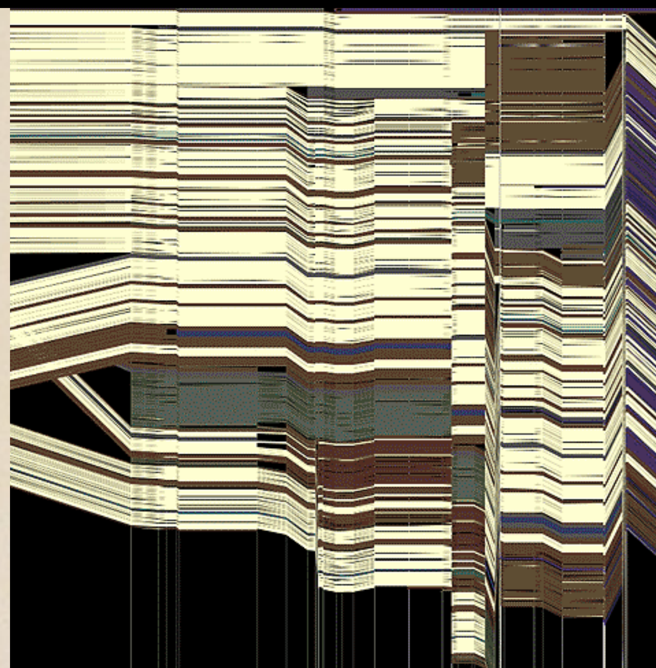
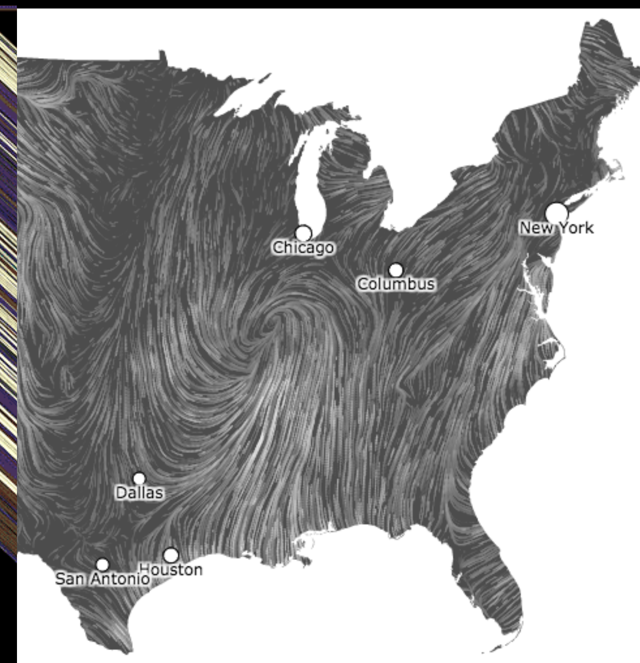
CSE 442 - Data Visualization

Graphical Perception







Jeffrey Heer University of Washington

Design Principles [Mackinlay 86]

Expressiveness
A set of facts is *expressible* in a visual language if the sentences (i.e. the visualizations) in the language express all the facts in the set of data, and only the facts in the data.

Effectiveness
A visualization is more *effective* than another visualization if the information conveyed by one visualization is more readily perceived than the information in the other visualization.

Design Principles *Translated*

Tell the truth and nothing but the truth
(don't lie, and don't lie by omission)

Use encodings that people decode better
(where better = faster and/or more accurate)

Which best encodes quantities?

Position

Length

Area

Volume

Value (Brightness)

Color Hue

Orientation (Angle)

Shape

Effectiveness Rankings [Mackinlay 86]

QUANTITATIVE	ORDINAL	NOMINAL
Position	Position	Position
Length	Density (Value)	Color Hue
Angle	Color Sat	Texture
Slope	Color Hue	Connection
Area (Size)	Texture	Containment
Volume	Connection	Density (Value)
Density (Value)	Containment	Color Sat
Color Sat	Length	Shape
Color Hue	Angle	Length
Texture	Slope	Angle
Connection	Area (Size)	Slope
Containment	Volume	Area
Shape	Shape	Volume

Graphical Perception

The ability of viewers to interpret visual (graphical) encodings of information and thereby decode information in graphs.

Topics

Signal Detection
Magnitude Estimation
Pre-Attentive Processing
Using Multiple Visual Encodings
Gestalt Grouping
Change Blindness

Detection

Detecting Brightness

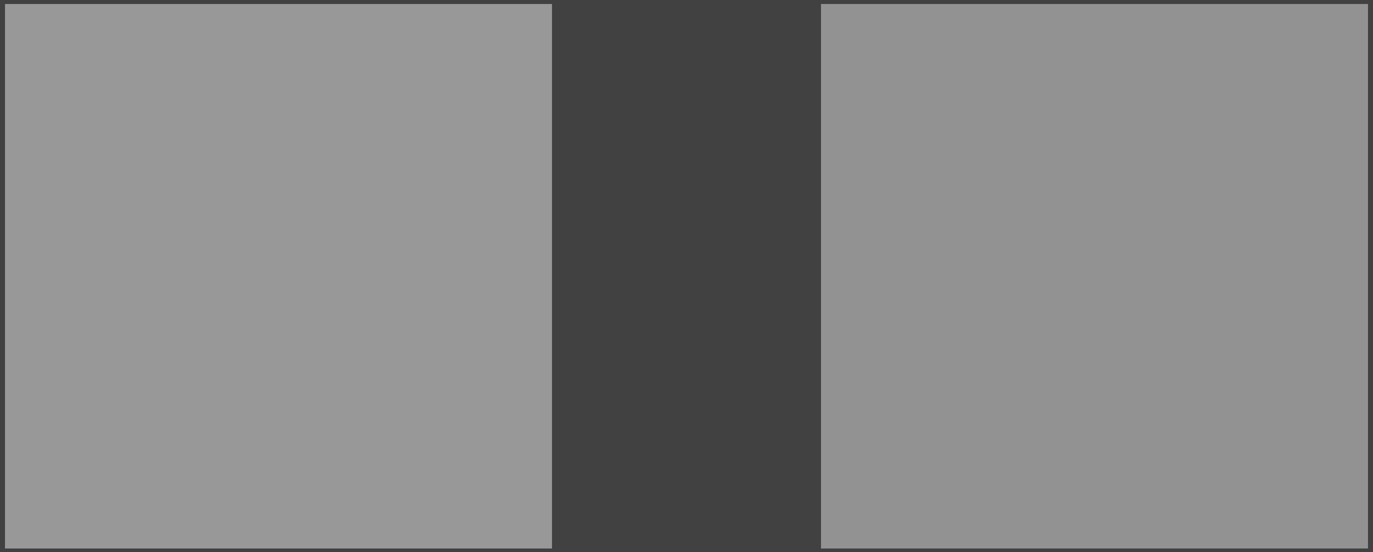
Which is brighter?

Detecting Brightness

(128, 128, 128) (144, 144, 144)

Which is brighter?

Detecting Brightness



Which is brighter?

Detecting Brightness

(134, 134, 134)   (128, 128, 128)

Which is brighter?

Just Noticeable Difference (JND)

JND (Weber's Law)

$$\Delta S = k \frac{\Delta I}{I}$$

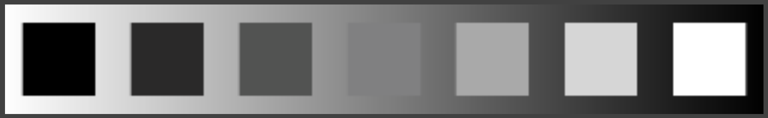
Ratios more important than magnitude

Most continuous variation in stimuli are perceived in discrete steps

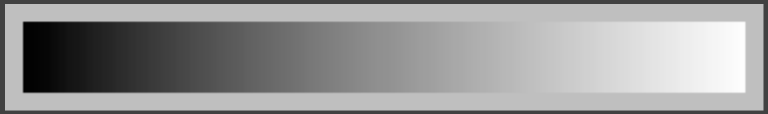
Encoding Data with Color

Value is perceived as ordered

∴ Encode ordinal variables (O)



∴ Encode continuous variables (Q) [not as well]



Hue is normally perceived as unordered

∴ Encode nominal variables (N) using color

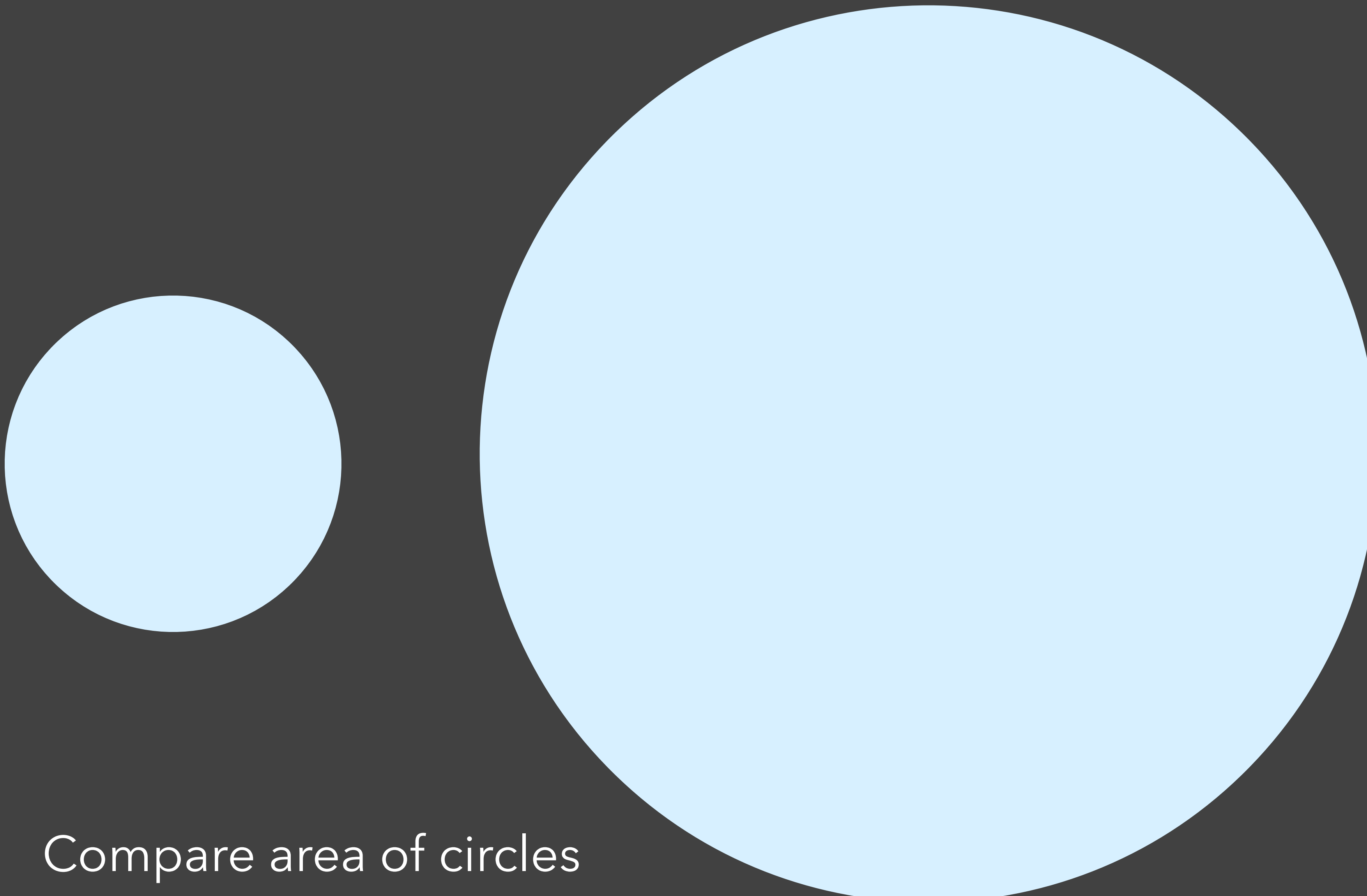
Steps in Font Size

Sizes standardized in 16th century

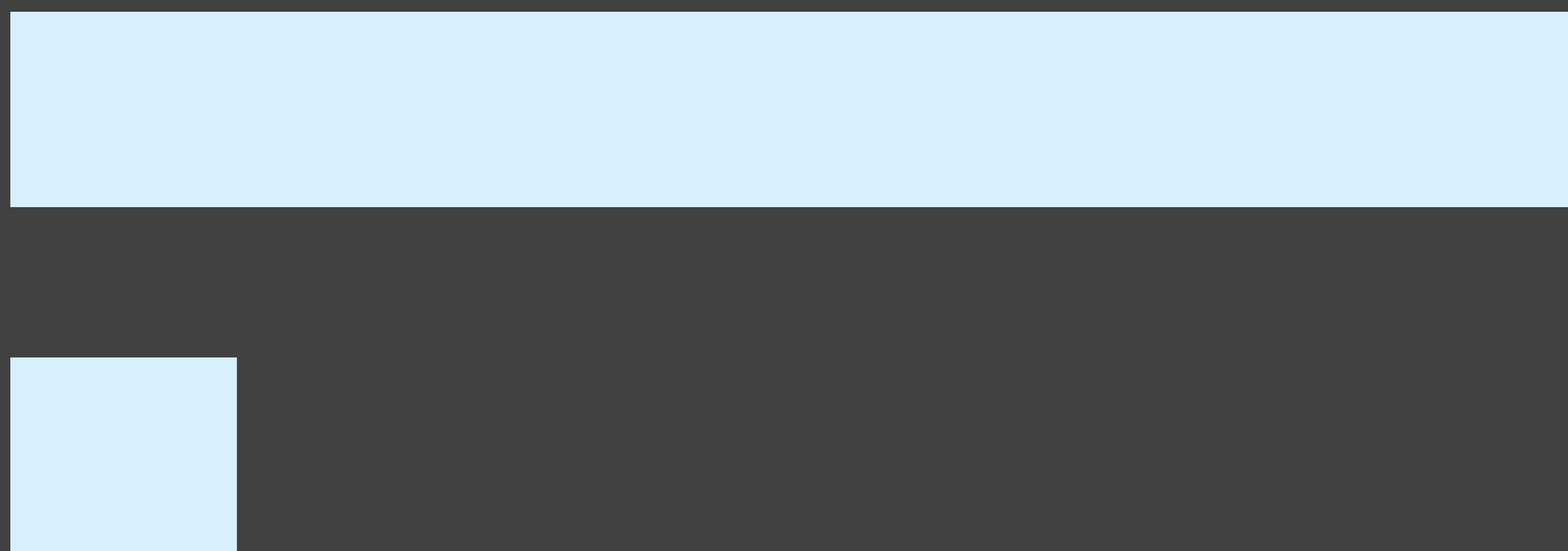
a	a	a	a	a	a	a	a	a	a	a	a	a	a	a	a
6	7	8	9	10	11	12	14	16	18	21	24	36	48	60	72

Magnitude Estimation

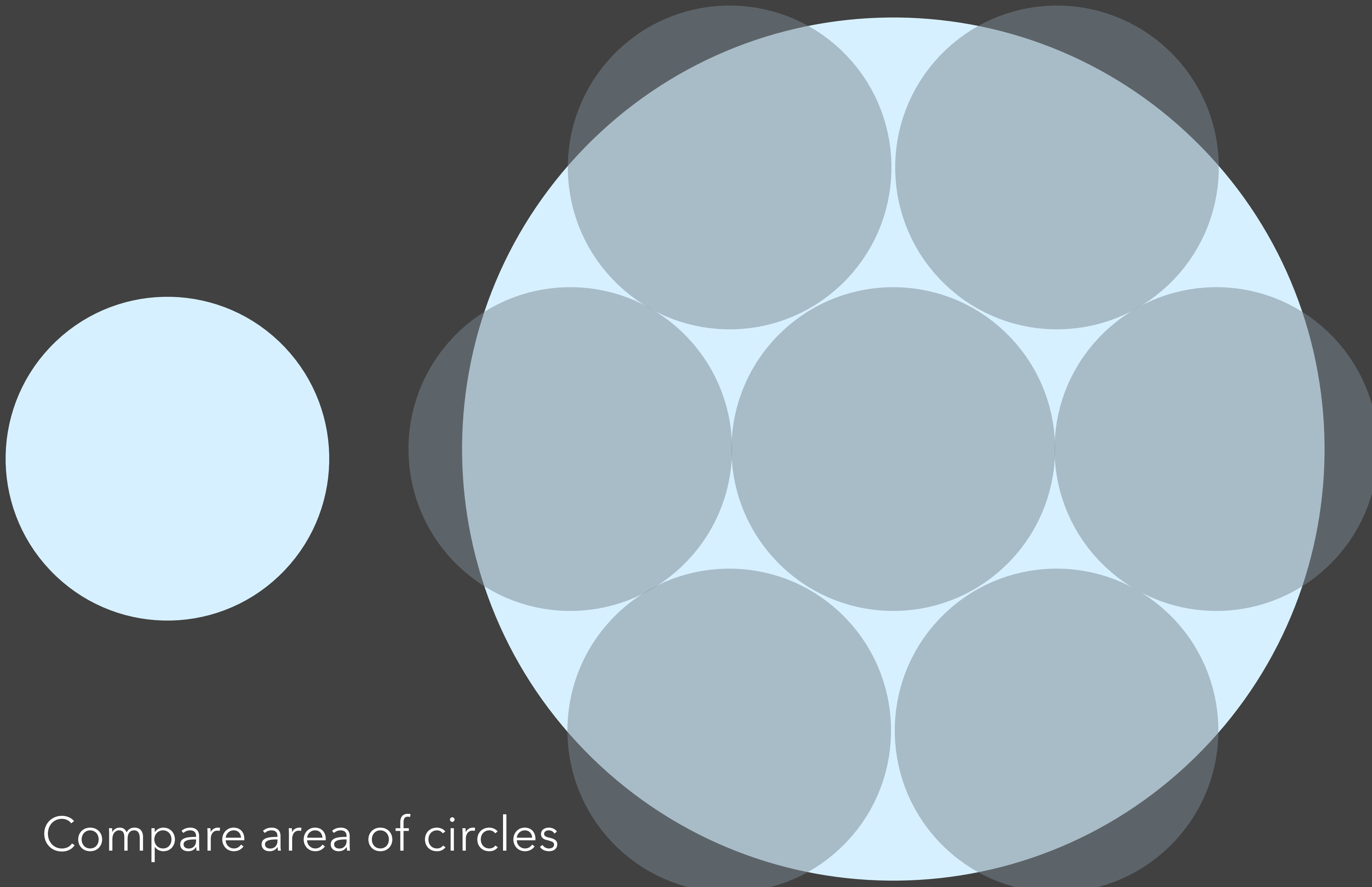
A Quick Experiment…

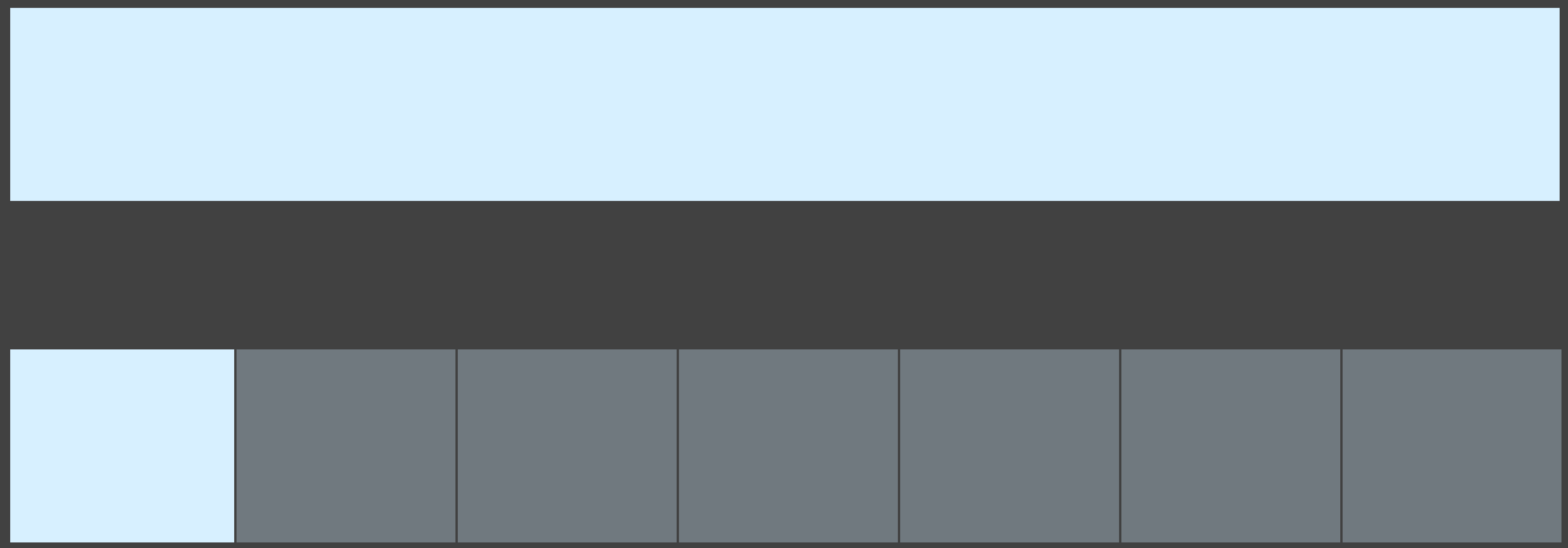


Compare area of circles



Compare length of bars


Compare area of circles



Compare length of bars

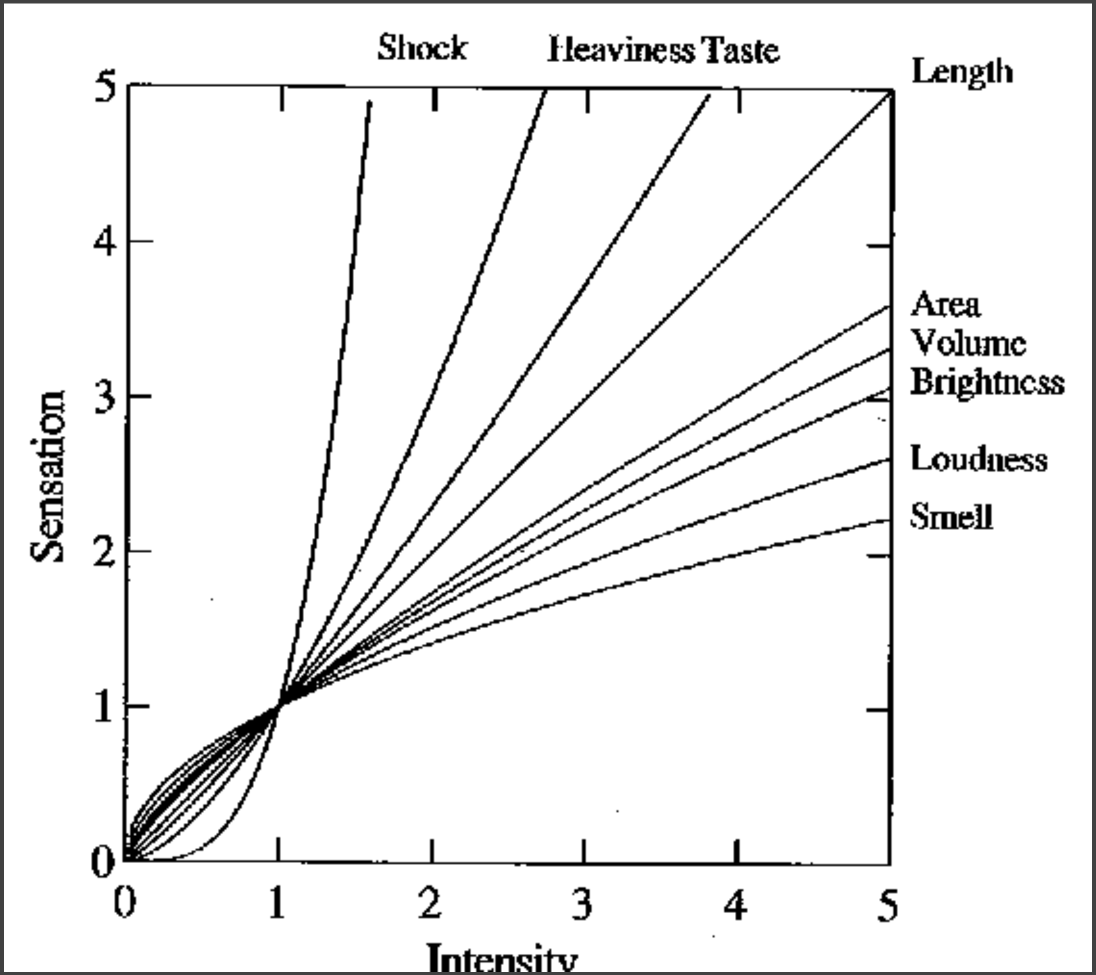
Steven's Power Law

Exponent
(Empirically Determined)

$$S = I^p$$

Perceived Sensation — Physical Intensity

Predicts bias, not necessarily accuracy!



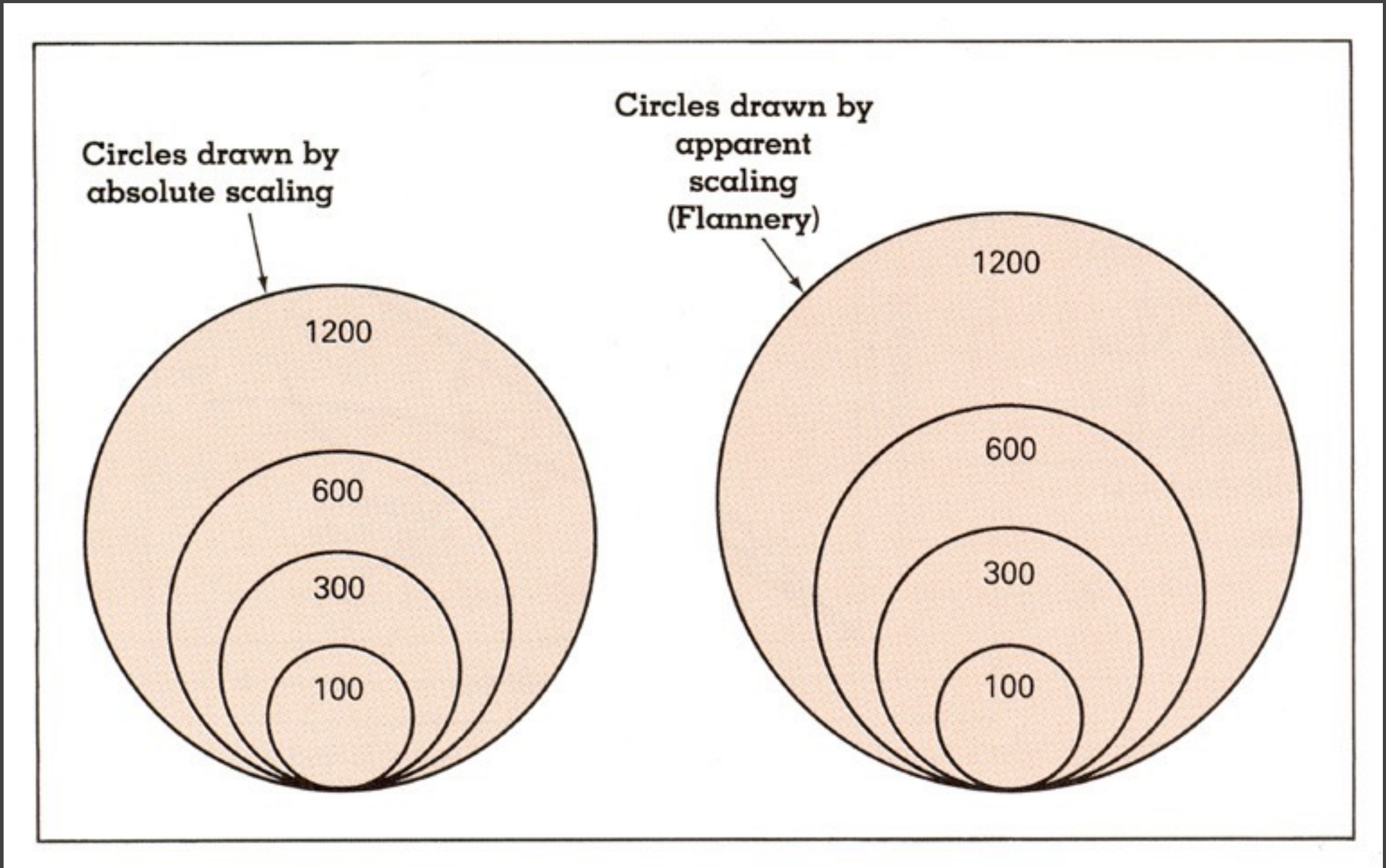
[Graph from Wilkinson 99, based on Stevens 61]

Exponents of Power Law

Sensation	Exponent
Loudness	0.6
Brightness	0.33
Smell	0.55 (Coffee) - 0.6 (Heptane)
Taste	0.6 (Saccharine) -1.3 (Salt)
Temperature	1.0 (Cold) – 1.6 (Warm)
Vibration	0.6 (250 Hz) – 0.95 (60 Hz)
Duration	1.1
Pressure	1.1
Heaviness	1.45
Electic Shock	3.5

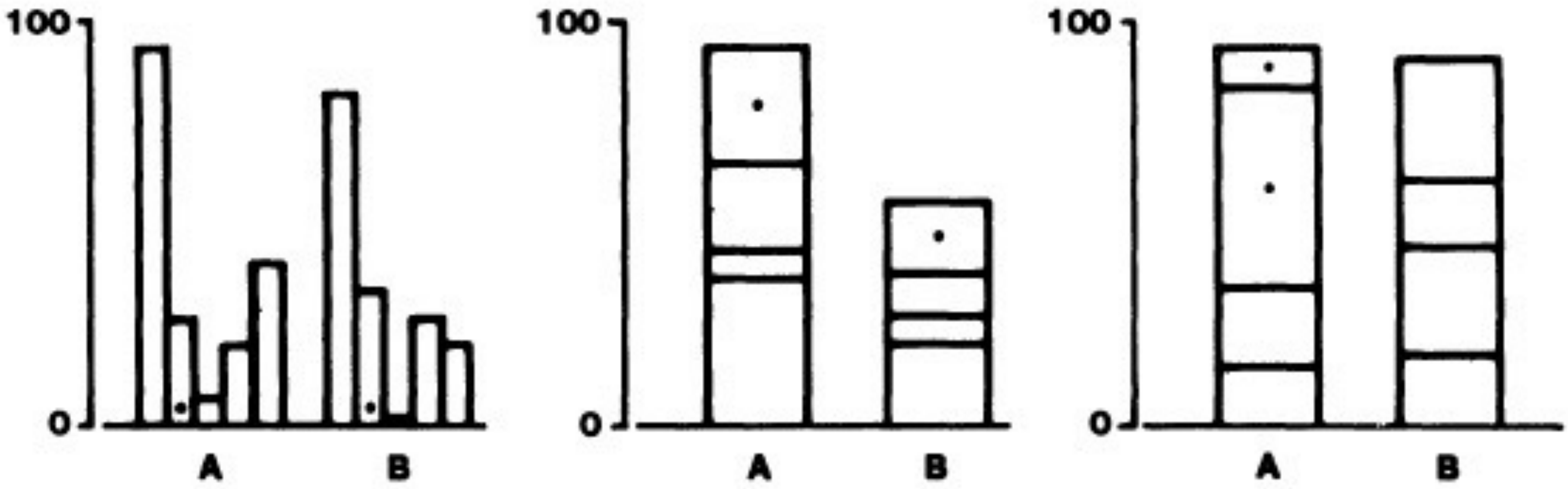
[Psychophysics of Sensory Function, Stevens 61]

Apparent Magnitude Scaling



[Cartography: Thematic Map Design, Figure 8.6, p. 170, Dent, 96]

$\boldsymbol{S = 0.98A^{0.87}}$ [from Flannery 71]



Graphical Perception [Cleveland & McGill 84]

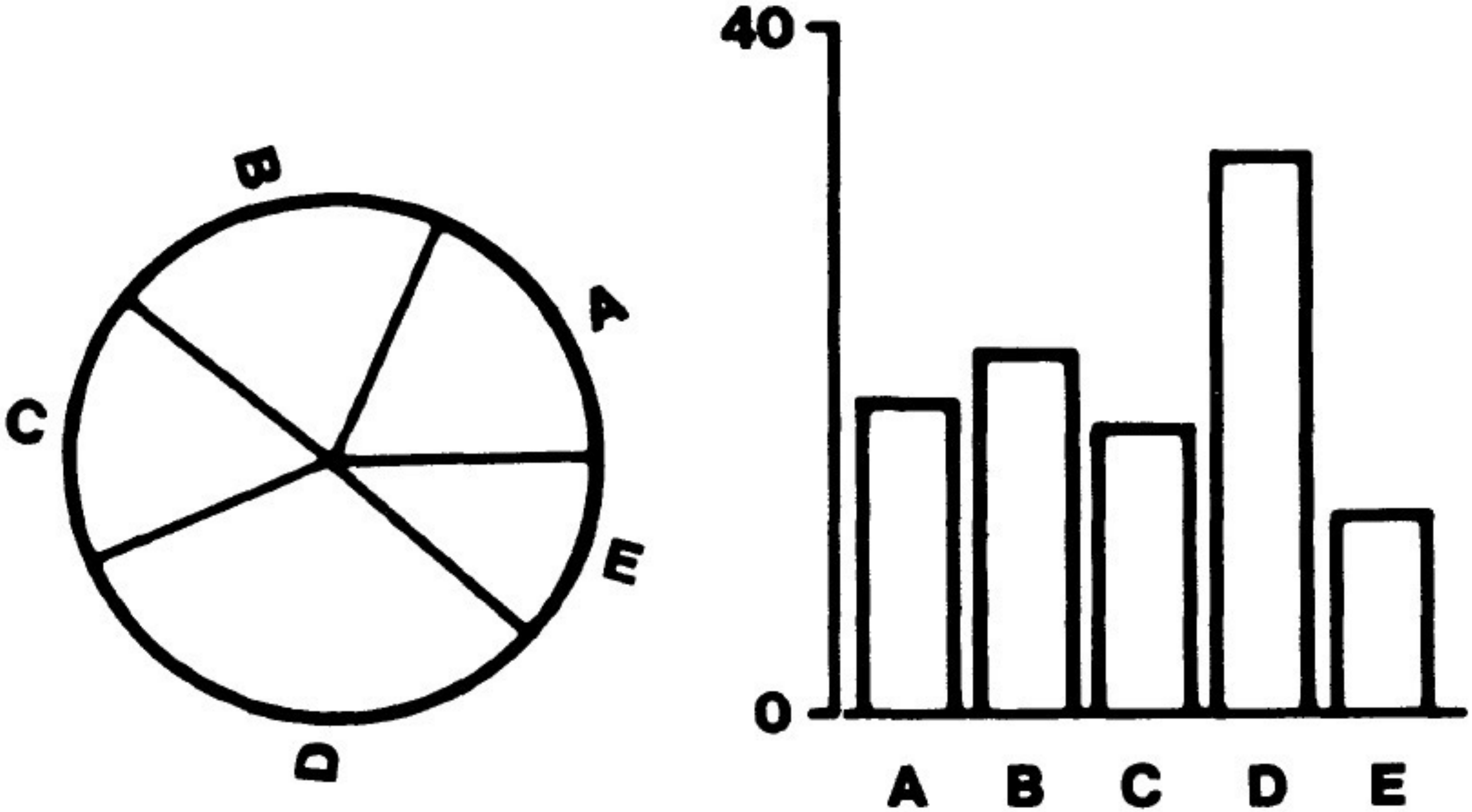
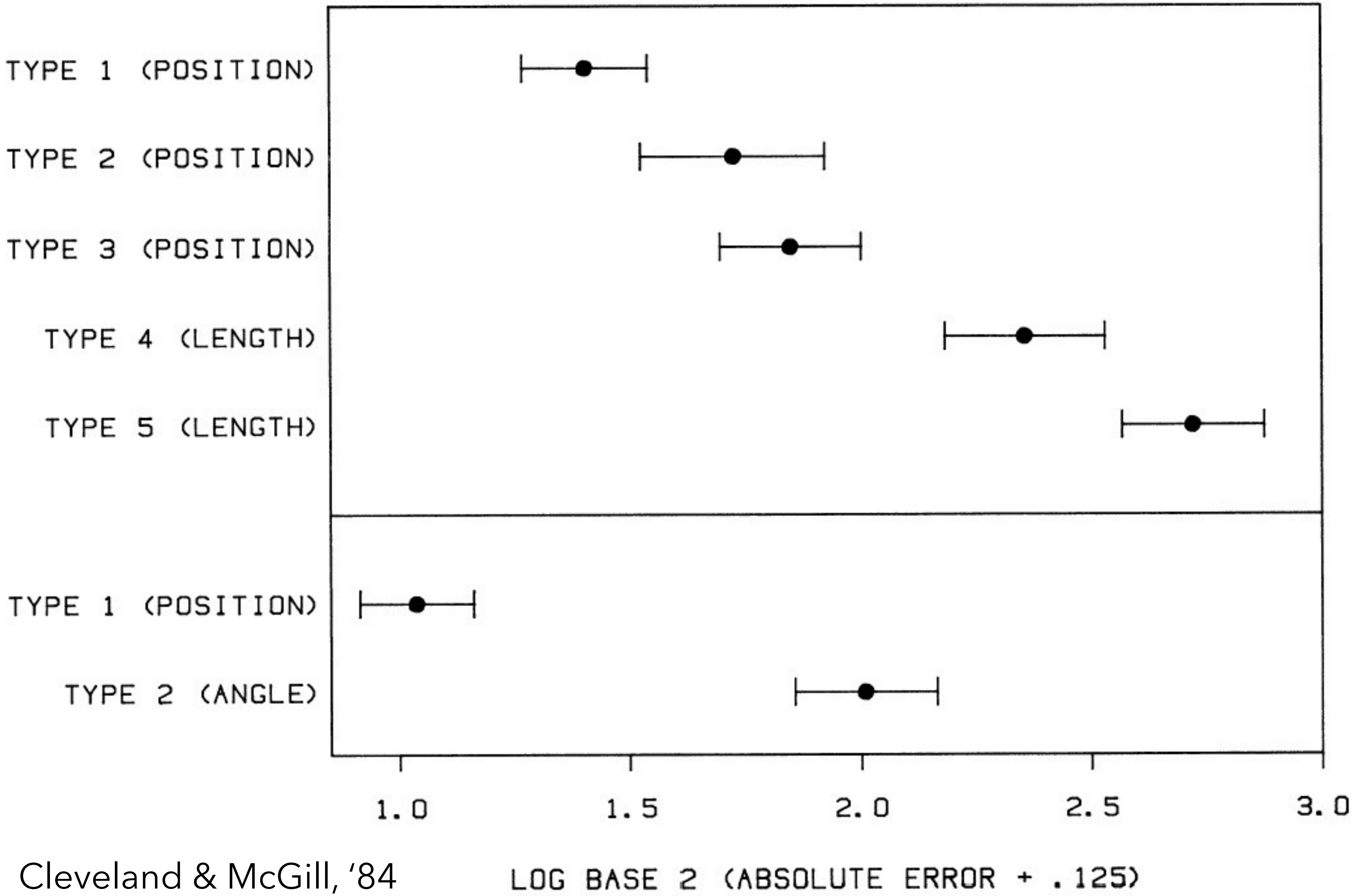
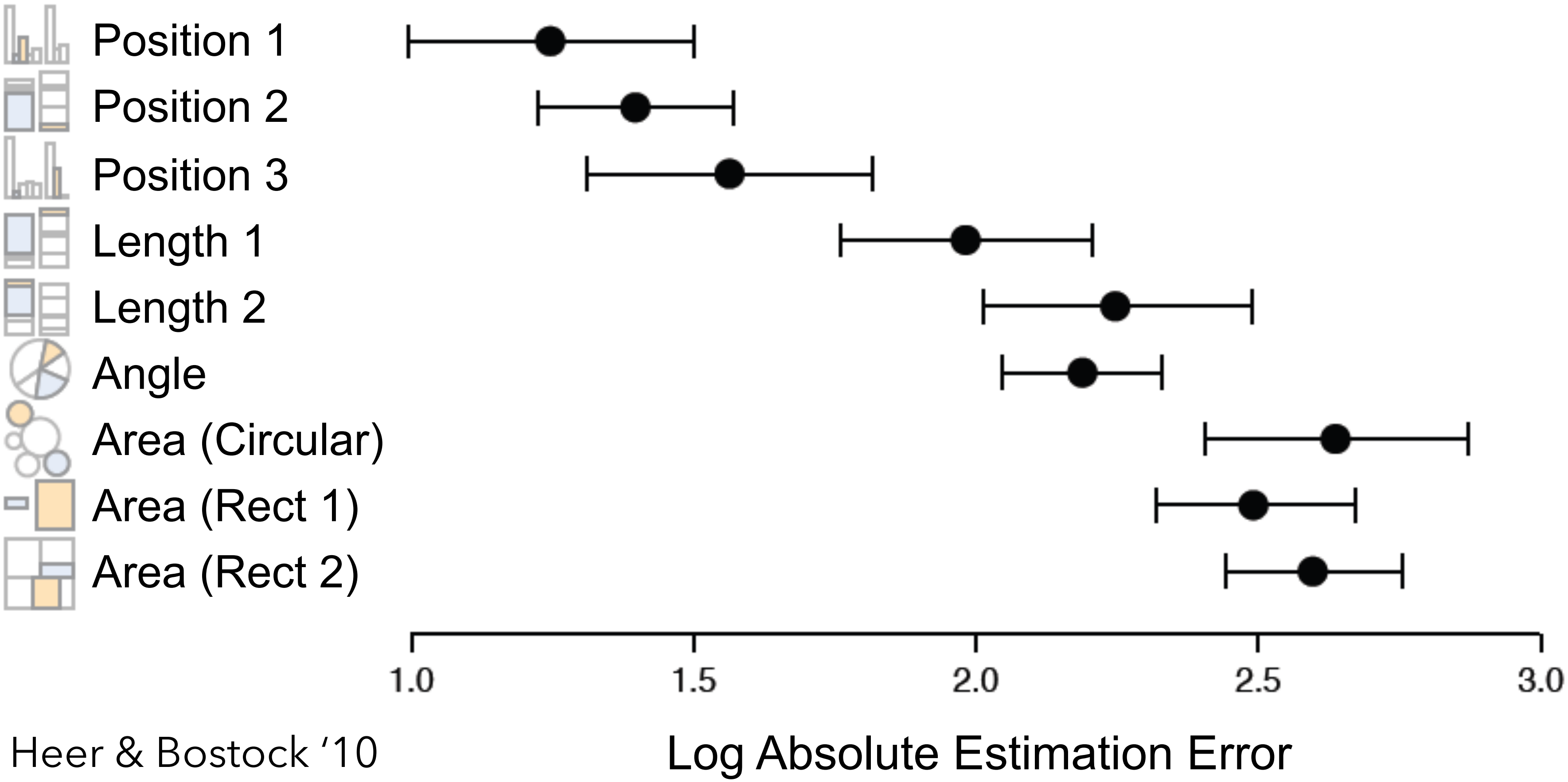


Figure 3. Graphs from position–angle experiment.



Cleveland & McGill, '84

Figure 16. Log absolute error means and 95% confidence intervals for judgment types in position–length experiment (top) and position–angle experiment (bottom).



Heer & Bostock '10

Graphical Perception Experiments

Empirical estimates of encoding effectiveness

Relative Magnitude Comparison

Most accurate

Position (common) scale

Position (non-aligned) scale

Length

Slope

Angle

Area

Volume

Color hue-saturation-density

Least accurate

Effectiveness Rankings [Mackinlay 86]

QUANTITATIVE	ORDINAL	NOMINAL
Position	Position	Position
Length	Density (Value)	Color Hue
Angle	Color Sat	Texture
Slope	Color Hue	Connection
Area (Size)	Texture	Containment
Volume	Connection	Density (Value)
Density (Value)	Containment	Color Sat
Color Sat	Length	Shape
Color Hue	Angle	Length
Texture	Slope	Angle
Connection	Area (Size)	Slope
Containment	Volume	Area
Shape	Shape	Volume

Administrivia

A2: Exploratory Data Analysis

Use visualization software to form & answer questions

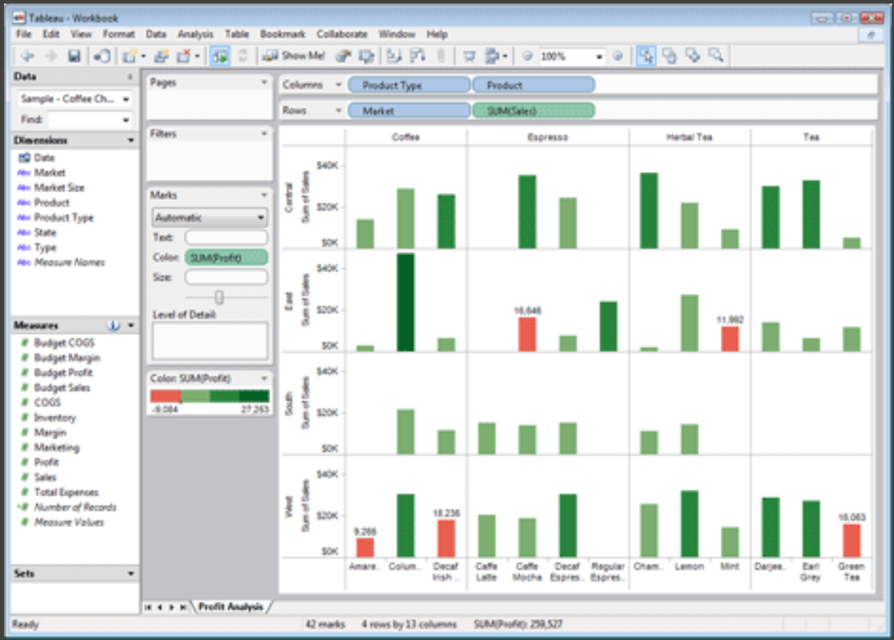
First steps: (Due Mon 4/10)

Step 1: Pick domain & data

Step 2: Pose questions

Step 3: Profile the data

Iterate as needed



Create visualizations

Interact with data

Refine your questions

Author a report

Screenshots of most insightful views *(10+)*

Include titles and captions for each view

~~Due by 11:59pm~~

~~**Friday, April 14**~~

Final Project Proposal

Project topic, goals, datasets & team members.

You should work in **teams of 3-4**.

Submit proposal form by **Tuesday 4/18, 5pm**.

If you do not have team mates, you should:

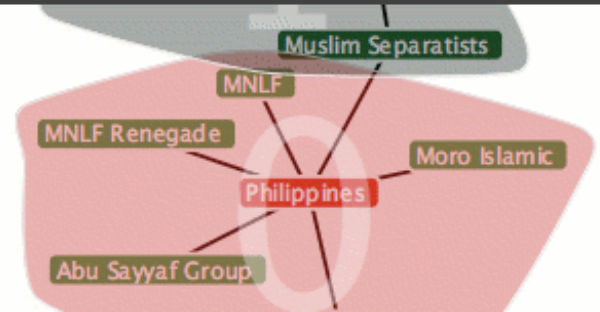
- Use the facilities on Canvas
- Stay after class to meet potential partners!

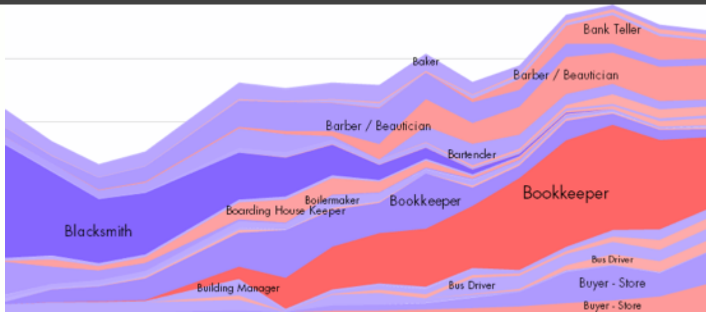
FP: Interactive Prototype

Create an interactive visualization. Choose a driving question in your topic area and develop an appropriate visualization + interaction techniques, then deploy your visualization on the web.

Due by *5pm* on **Wednesday, May 3**.

We will discuss in greater detail next time!





Pre-Attentive Processing

How Many 3's?

1281768756138976546984506985604982826762
9809858458224509856458945098450980943585
9091030209905959595772564675050678904567
8845789809821677654876364908560912949686

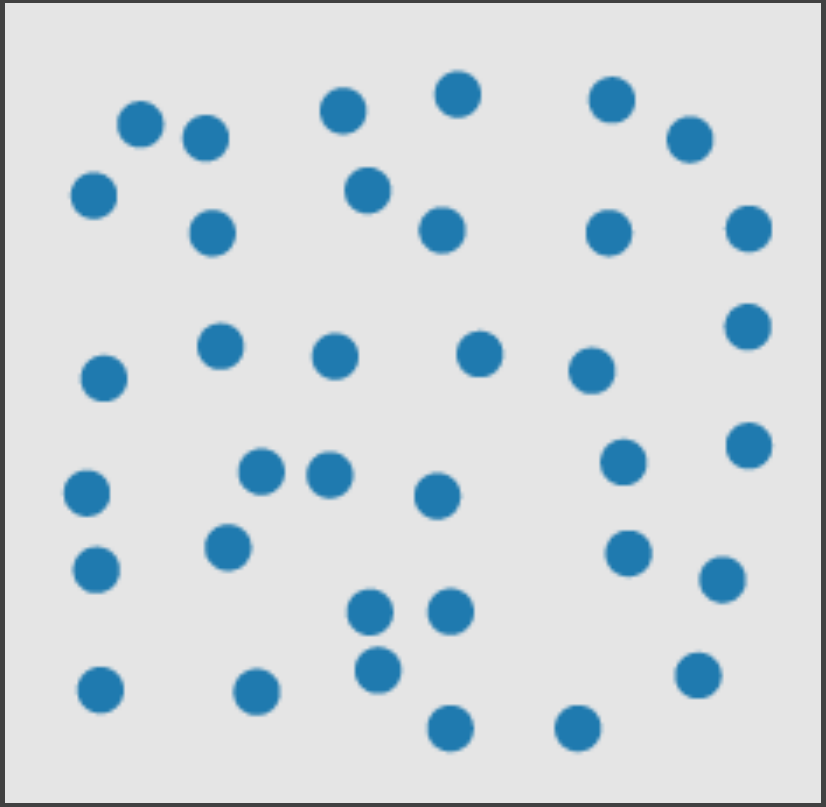
[based on a slide from J. Stasko]

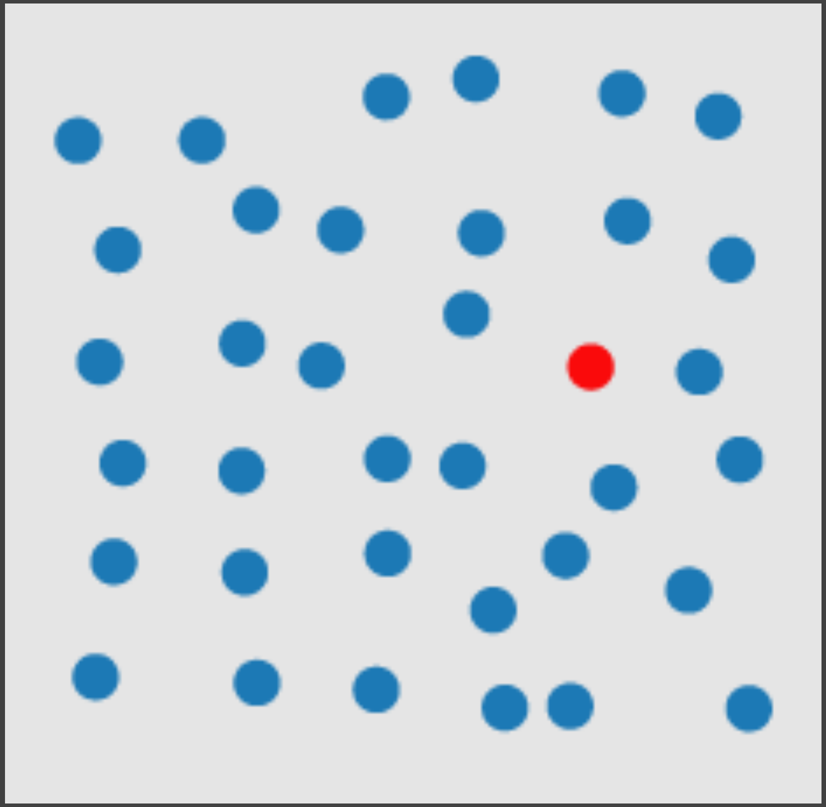
How Many 3's?

1281768756138976546984506985604982826762
9809858458224509856458945098450980943585
9091030209905959595772564675050678904567
8845789809821677654876364908560912949686

[based on a slide from J. Stasko]

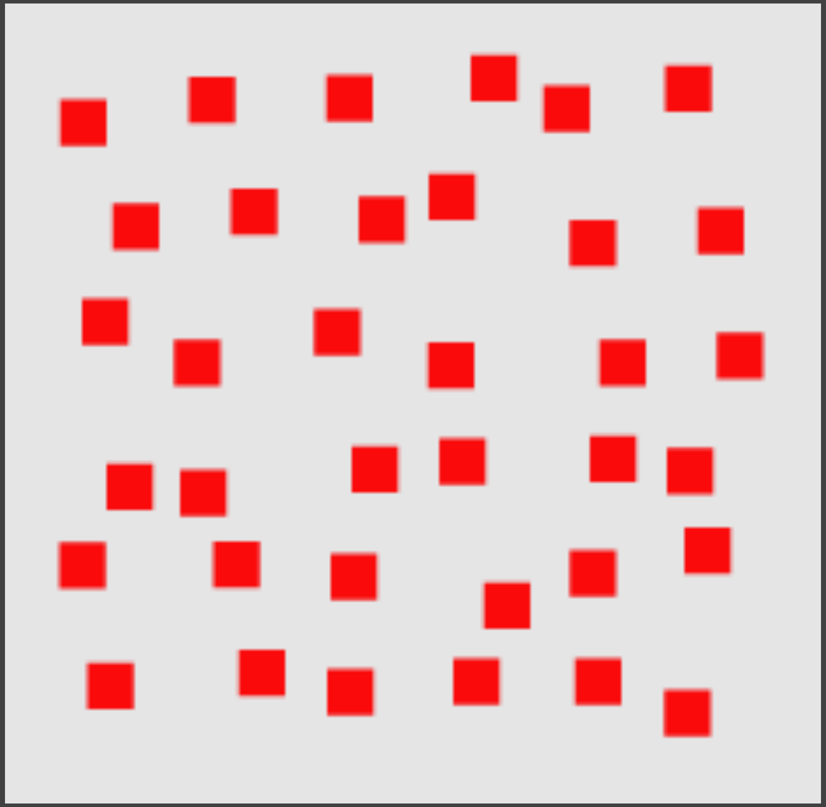
Visual Pop-Out: Color

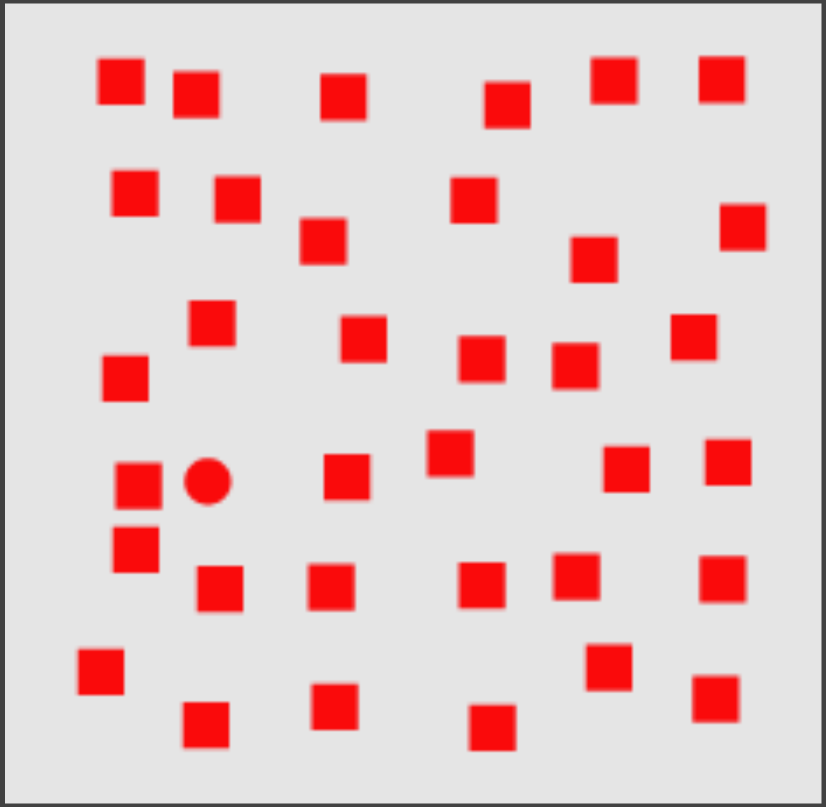




http://www.csc.ncsu.edu/faculty/healey/PP/index.html

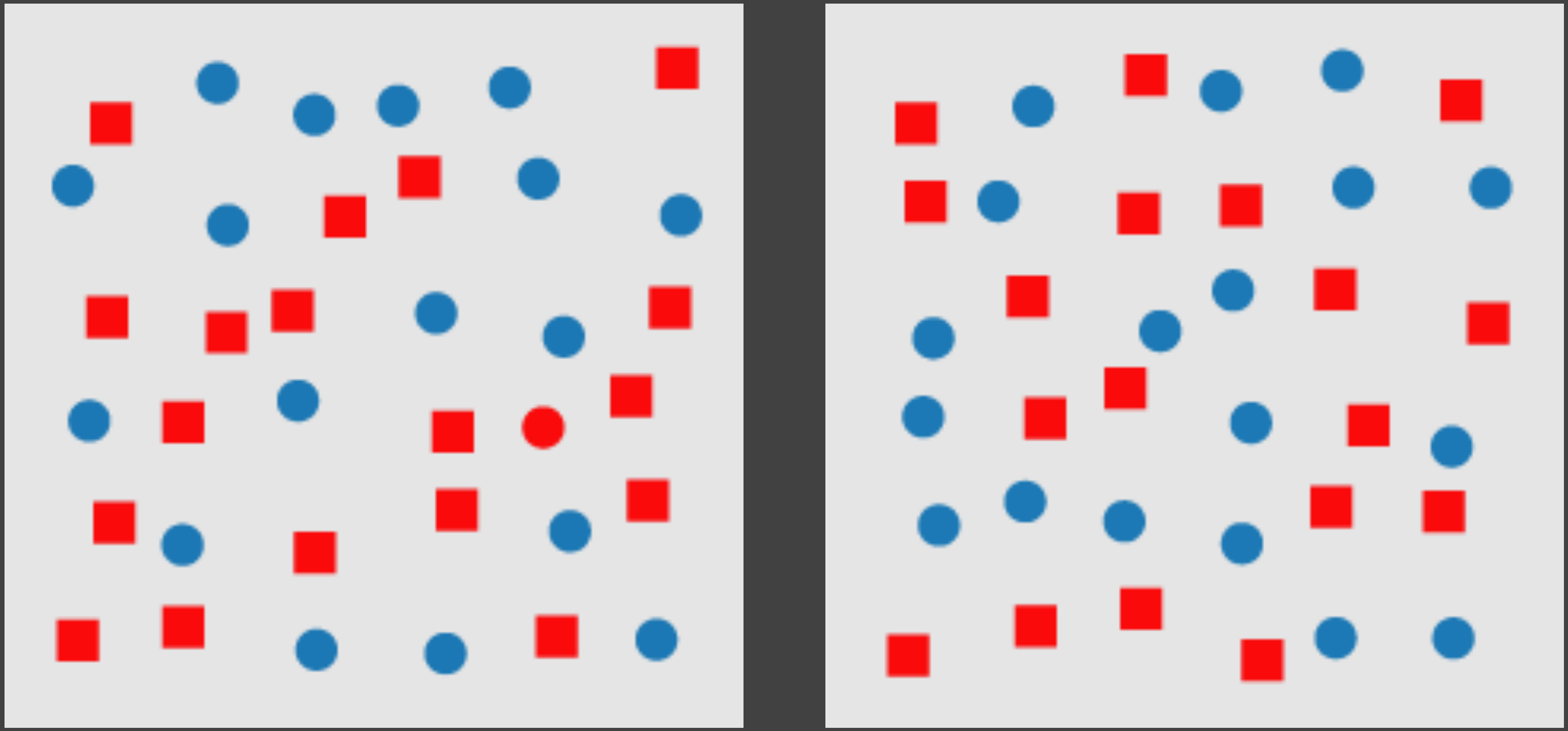
Visual Pop-Out: Shape





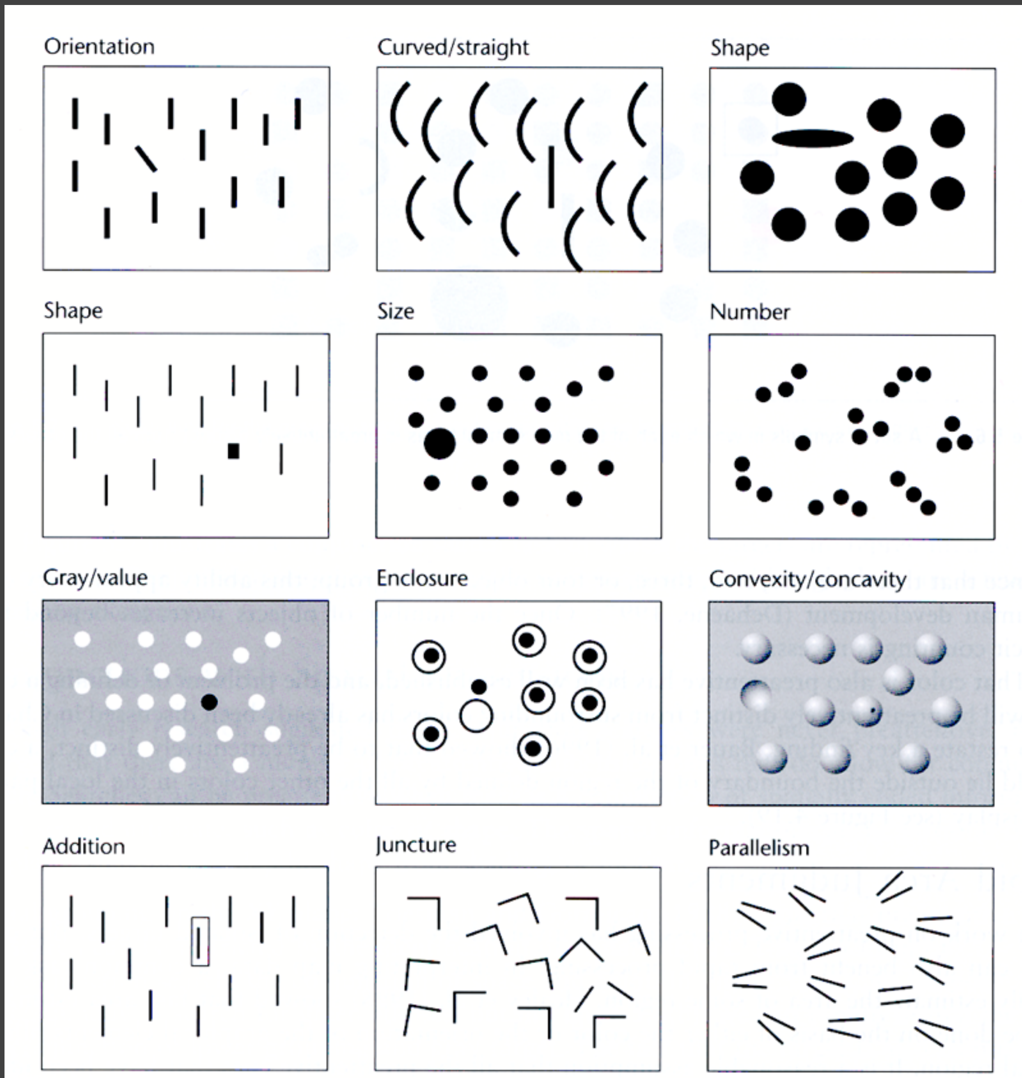
http://www.csc.ncsu.edu/faculty/healey/PP/index.html

Feature Conjunctions



http://www.csc.ncsu.edu/faculty/healey/PP/index.html

Pre-Attentive Features



[Information Visualization. Figure 5. 5 Ware 04]

More Pre-Attentive Features

Line (blob) orientation	Julesz & Bergen [1983]; Wolfe et al. [1992]
Length	Triesman & Gormican [1988]
Width	Julesz [1985]
Size	Triesman & Gelade [1980]
Curvature	Triesman & Gormican [1988]
Number	Julesz [1985]; Trick & Pylyshyn [1994]
Terminators	Julesz & Bergen [1983]
Intersection	Julesz & Bergen [1983]
Closure	Enns [1986]; Triesman & Souther [1985]
Colour (hue)	Nagy & Sanchez [1990, 1992]; D'Zmura [1991]; Kawai et al. [1995]; Bauer et al. [1996]
Intensity	Beck et al. [1983]; Triesman & Gormican [1988]
Flicker	Julesz [1971]
Direction of motion	Nakayama & Silverman [1986]; Driver & McLeod [1992]
Binocular lustre	Wolfe & Franzel [1988]
Stereoscopic depth	Nakayama & Silverman [1986]
3-D depth cues	Enns [1990]
Lighting direction	Enns [1990]

Pre-Attentive Conjunctions

Spatial conjunctions are often pre-attentive

Motion and 3D disparity

Motion and color

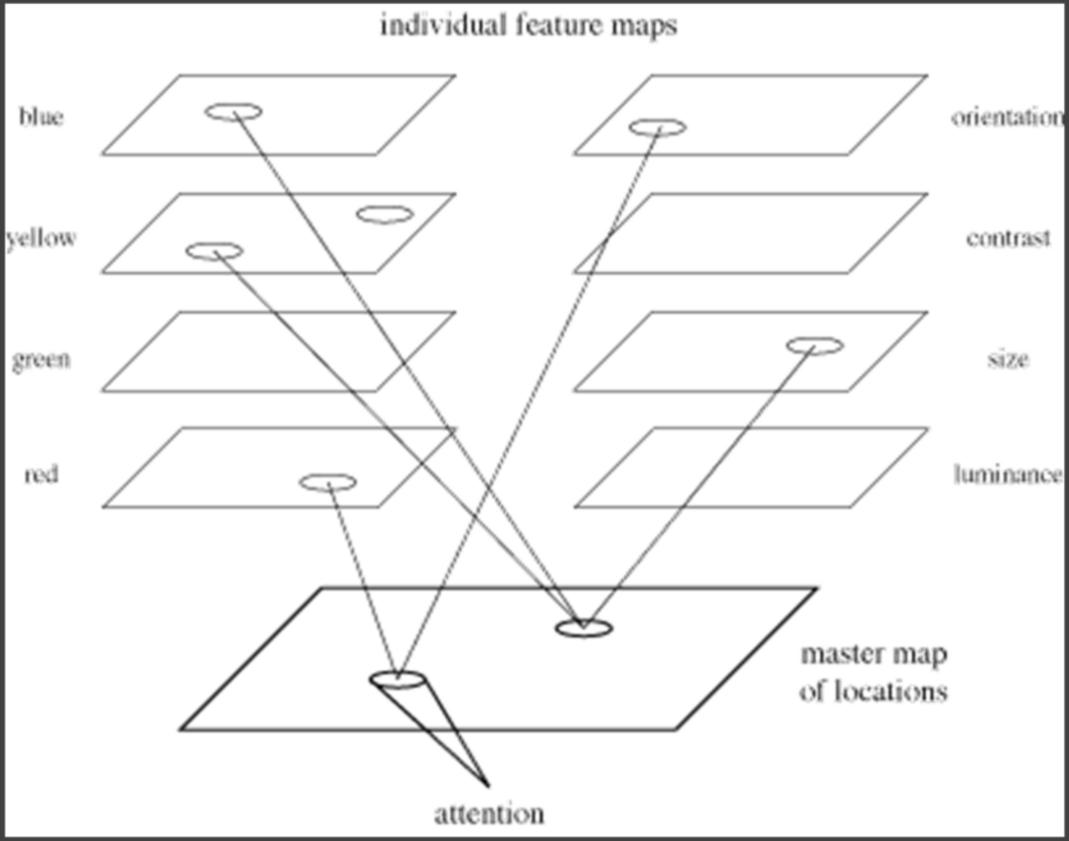
Motion and shape

3D disparity and color

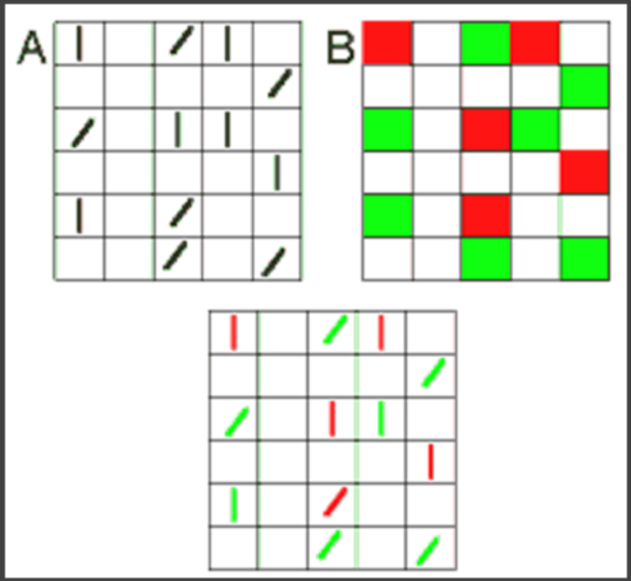
3D disparity and shape

Most conjunctions are not pre-attentive

Feature Integration Theory



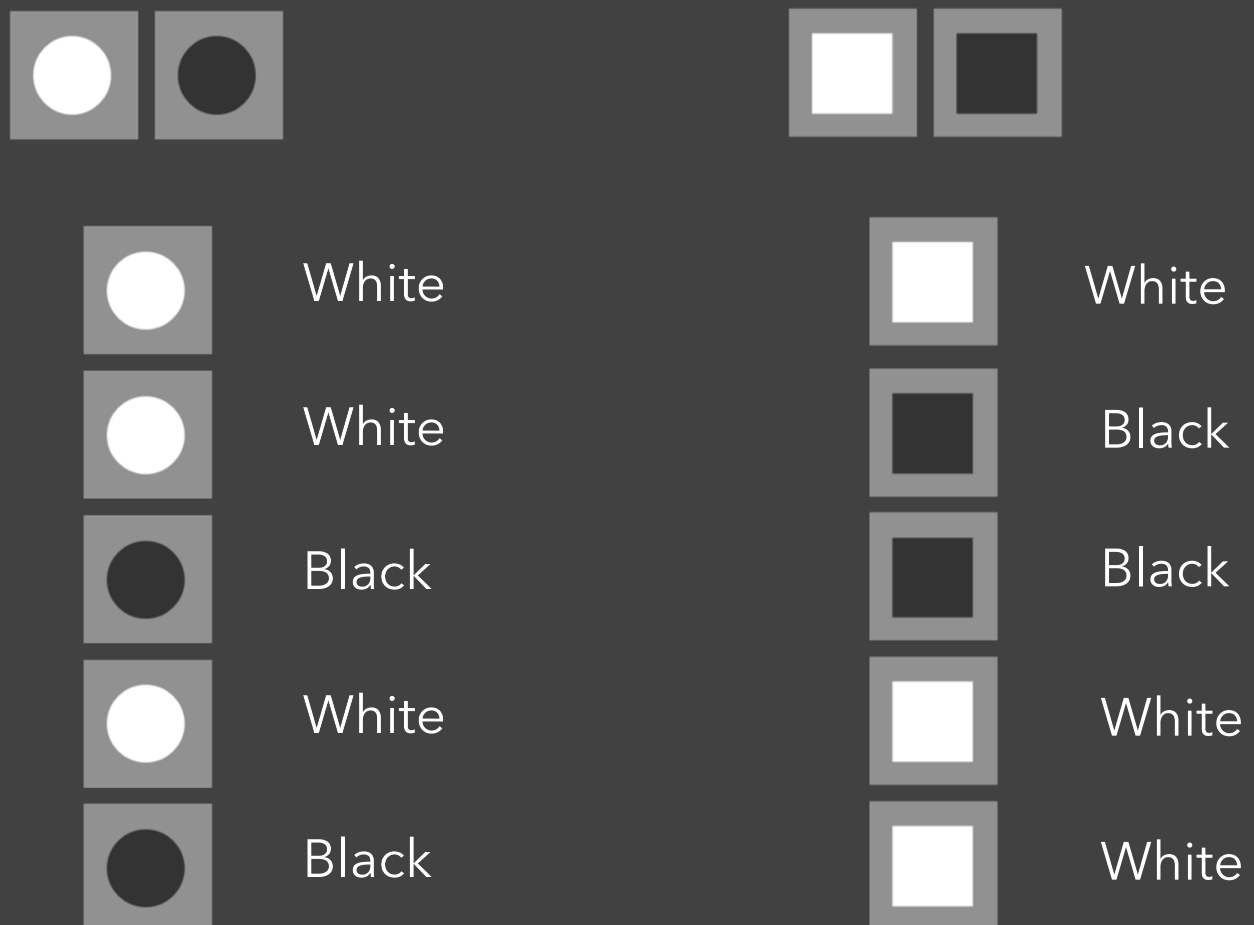
Treisman's feature integration model [Healey 04]



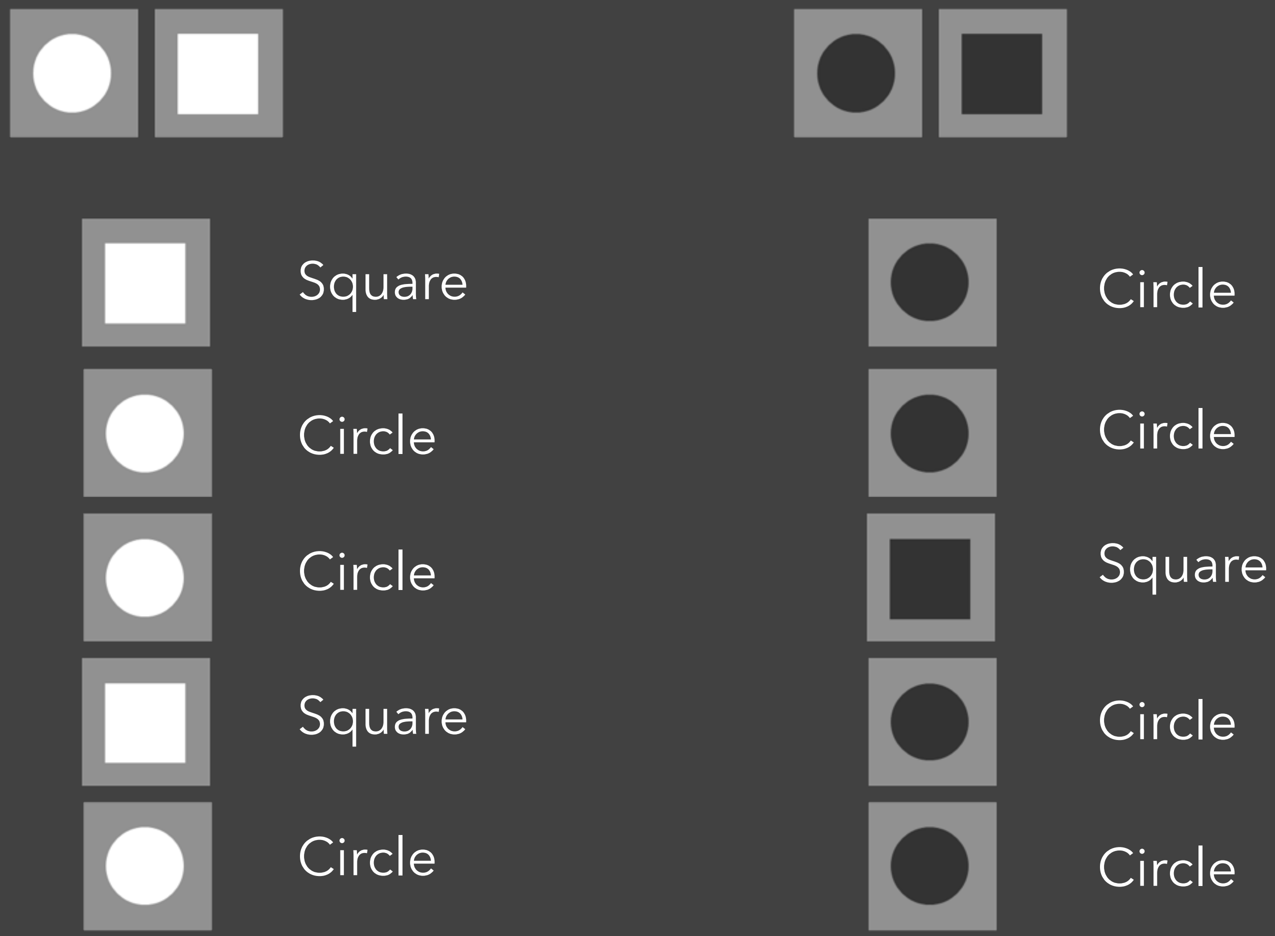
Feature maps for
orientation & color [Green]

Multiple Attributes

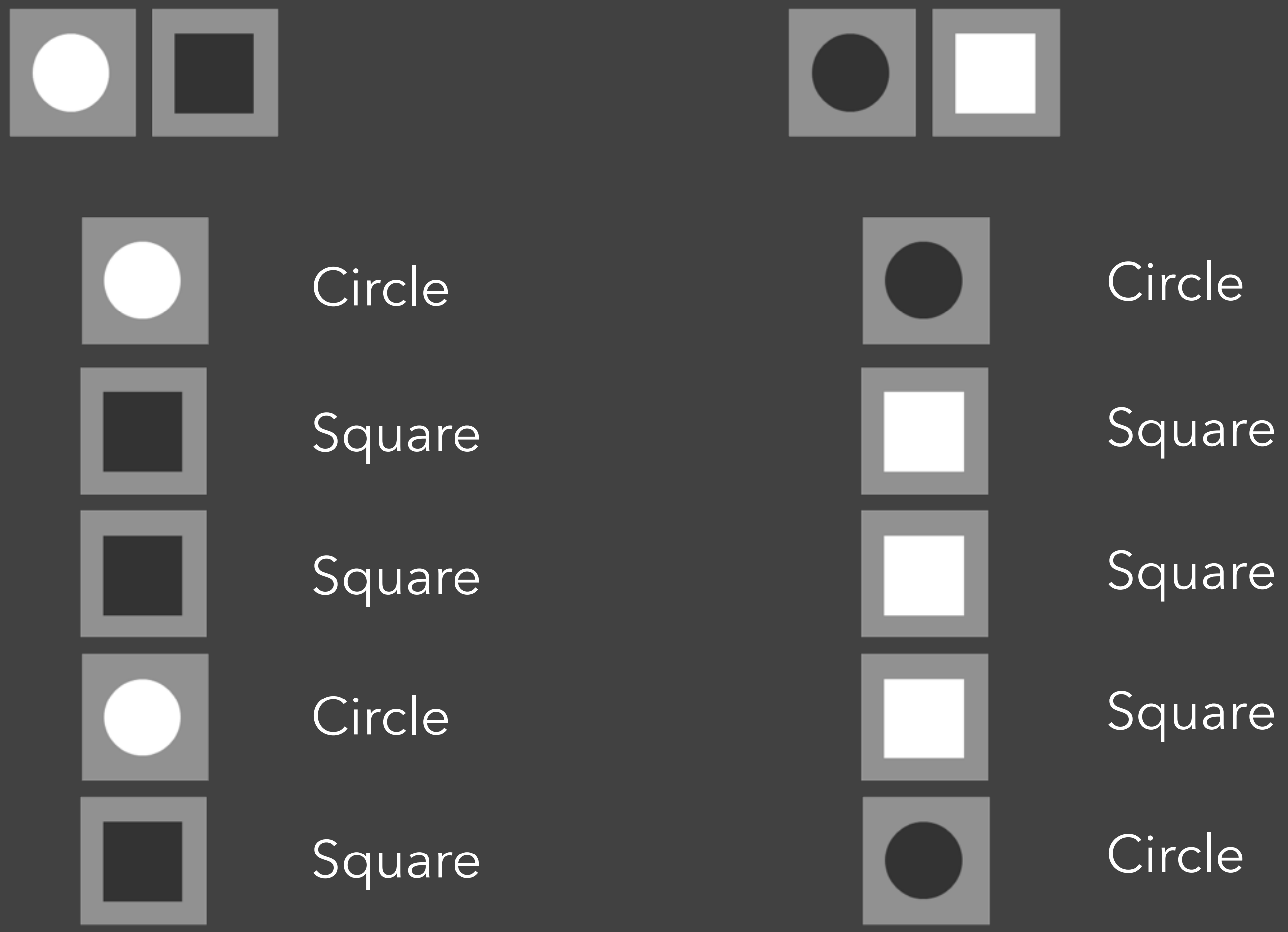
One-Dimensional: Lightness



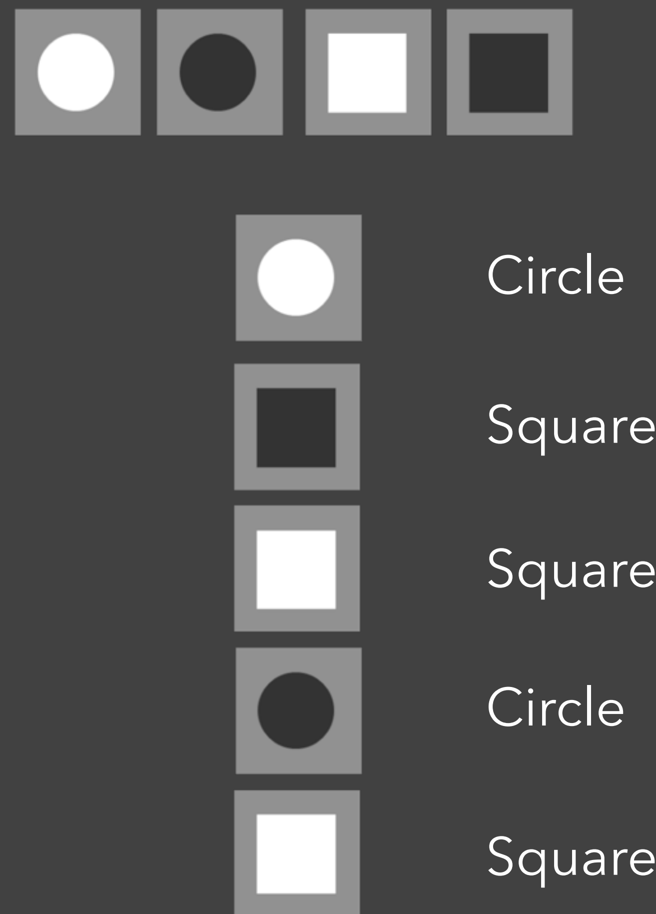
One-Dimensional: Shape



Redundant: Shape & Lightness



Orthogonal: Shape & Lightness



Speeded Classification

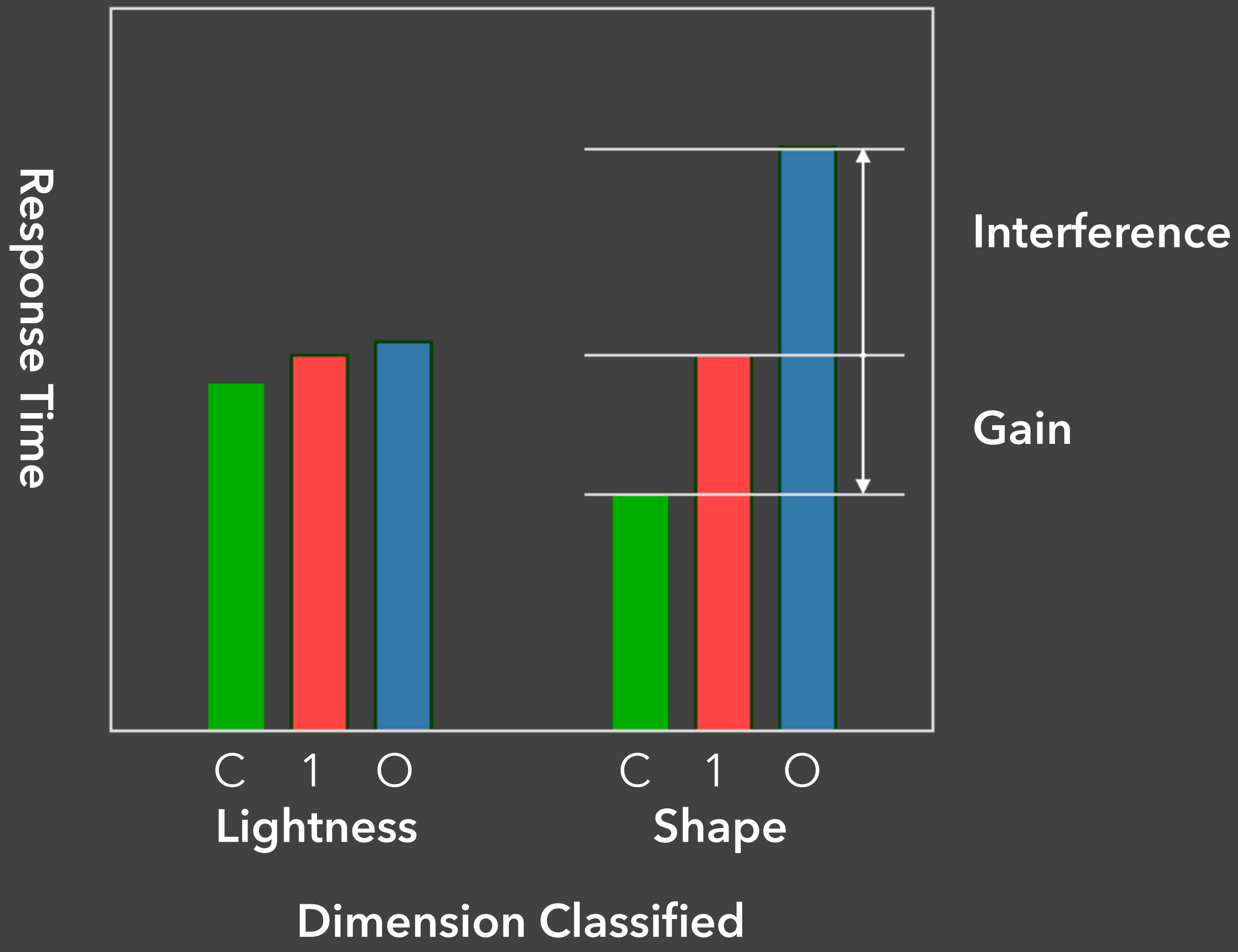
Redundancy Gain

Facilitation in reading one dimension when the other provides redundant information

Filtering Interference

Difficulty in ignoring one dimension while attending to the other

Speeded Classification



Types of Perceptual Dimensions

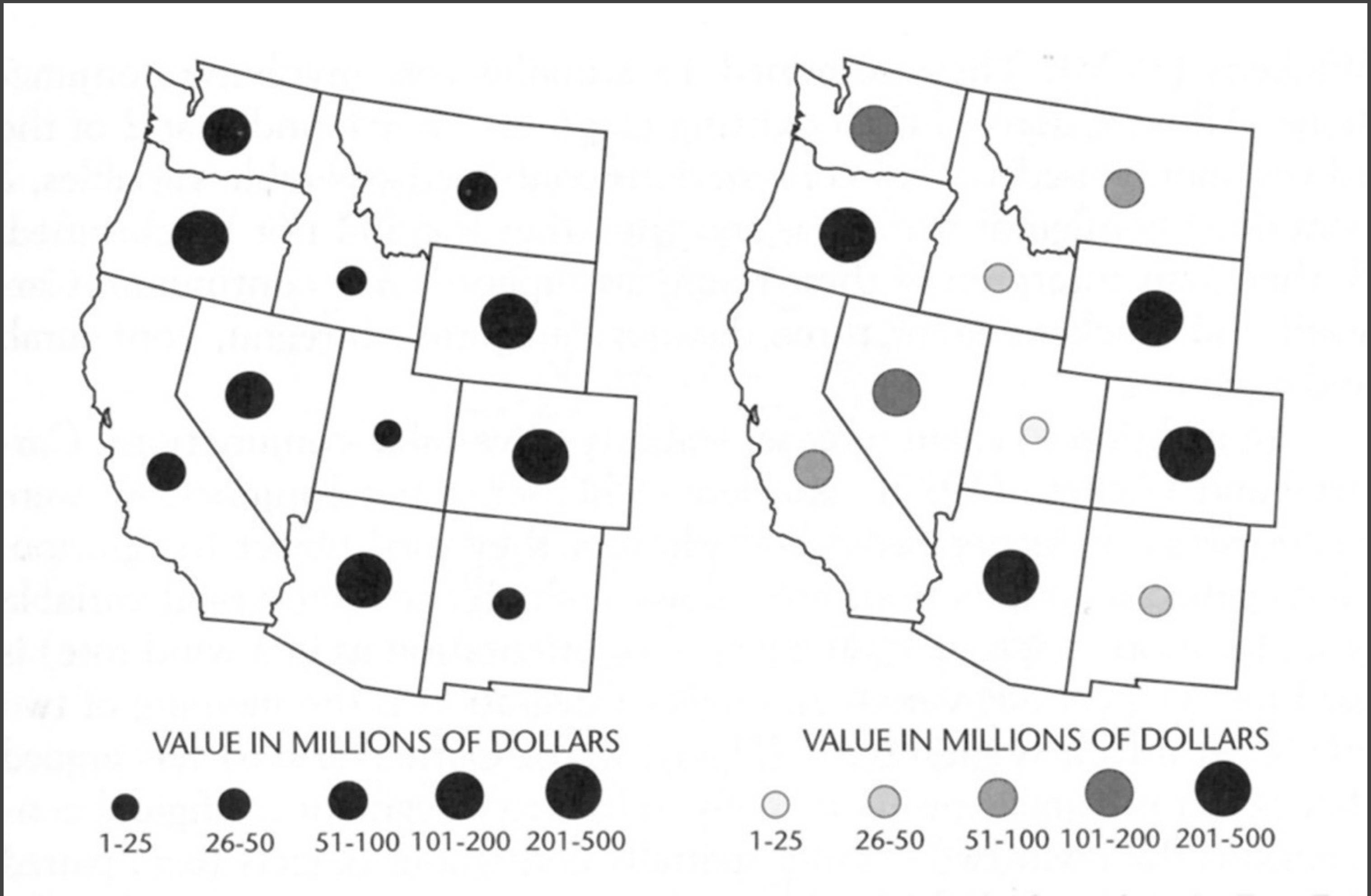
Integral
Filtering interference and redundancy gain

Separable
No interference or gain

Asymmetric
One dim separable from other, not vice versa

Example: The Stroop effect – color naming is influenced by word identity, but word naming is not influenced by color

Size and Value



W. S. Dobson, Visual information processing and cartographic communication: The role of redundant stimulus dimensions, 1983 (reprinted in MacEachren, 1995)

Orientation & Size

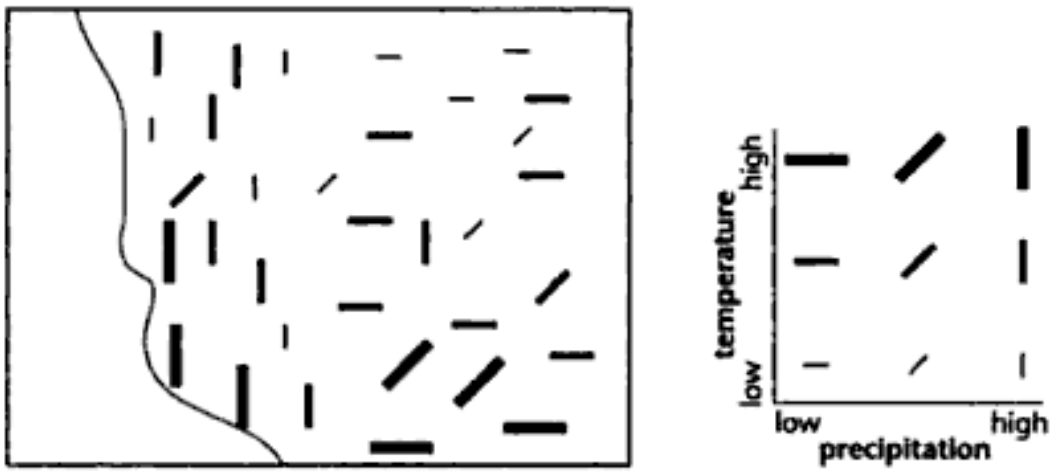


FIGURE 3.36. A map of temperature and precipitation using symbol size and orientation to represent data values on the two variables.

How well can you see temperature or precipitation?

Is there a correlation between the two?

[MacEachren 95]

Shape & Size

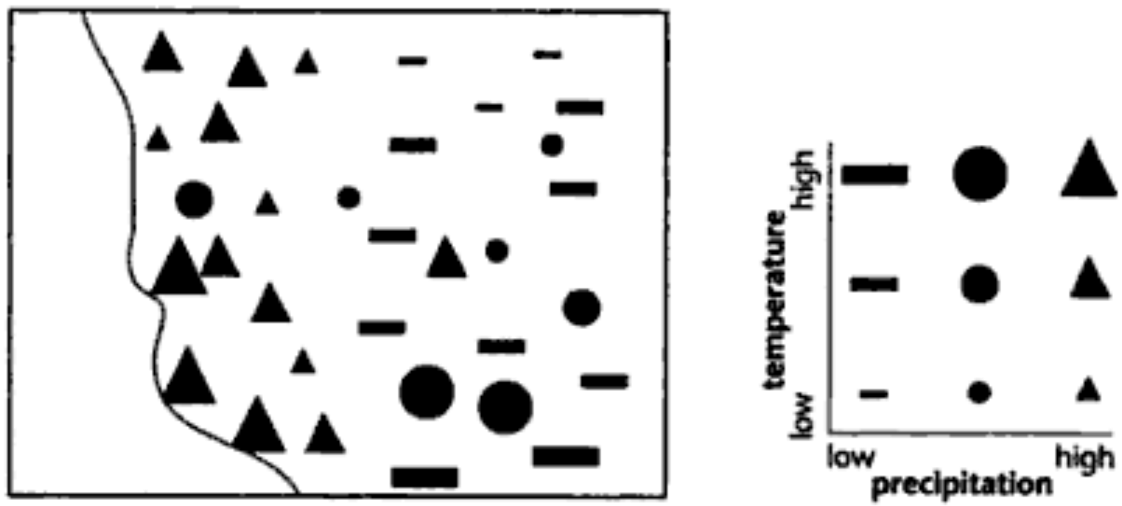


FIGURE 3.40. The bivariate temperature–precipitation map of Figure 3.36, this time using point symbols that vary in shape and size to represent the two quantities.

Easier to see one shape across multiple sizes than one size of across multiple shapes?

[MacEachren 95]

Length & Length

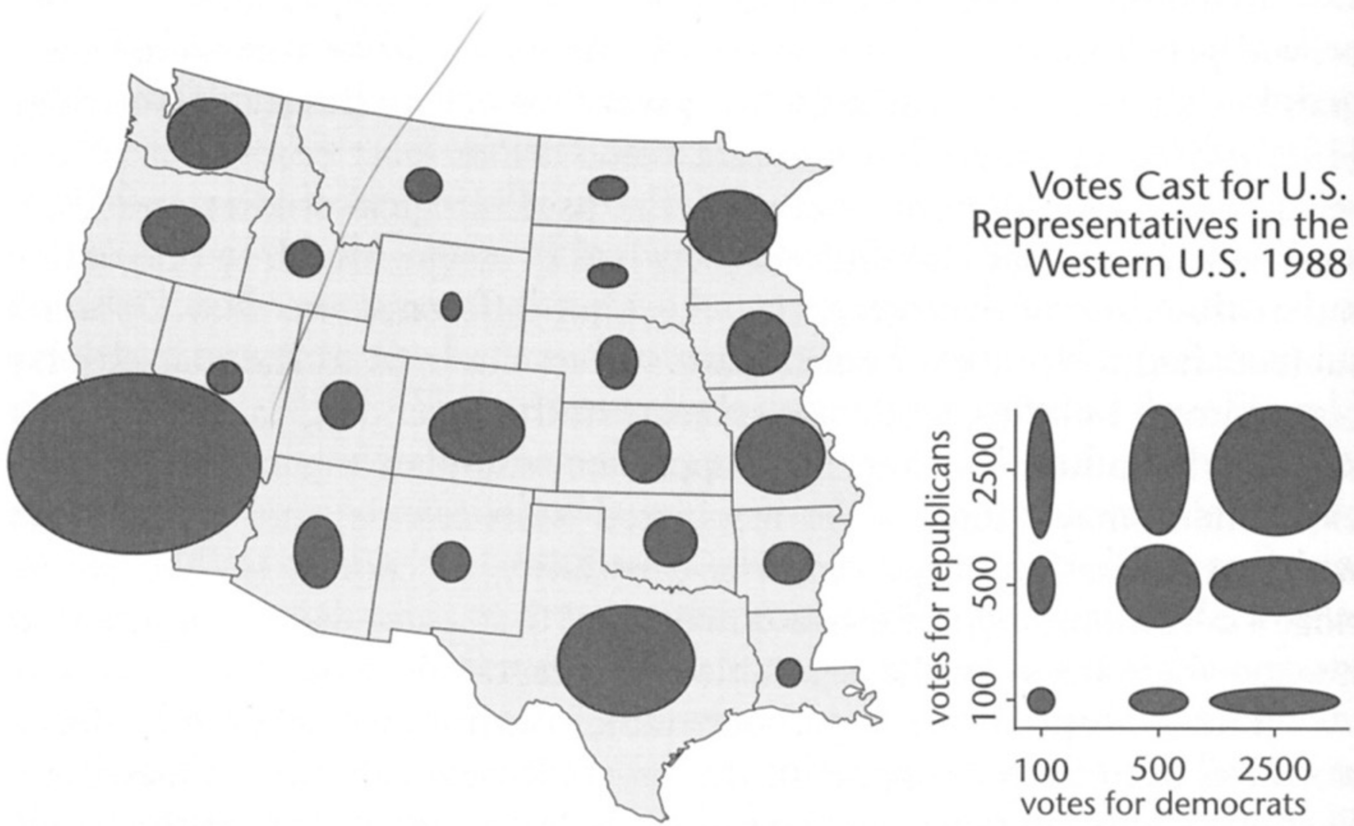


FIGURE 3.38. An example of the use of an ellipse as a map symbol in which the horizontal and vertical axes represent different (but presumably related) variables.

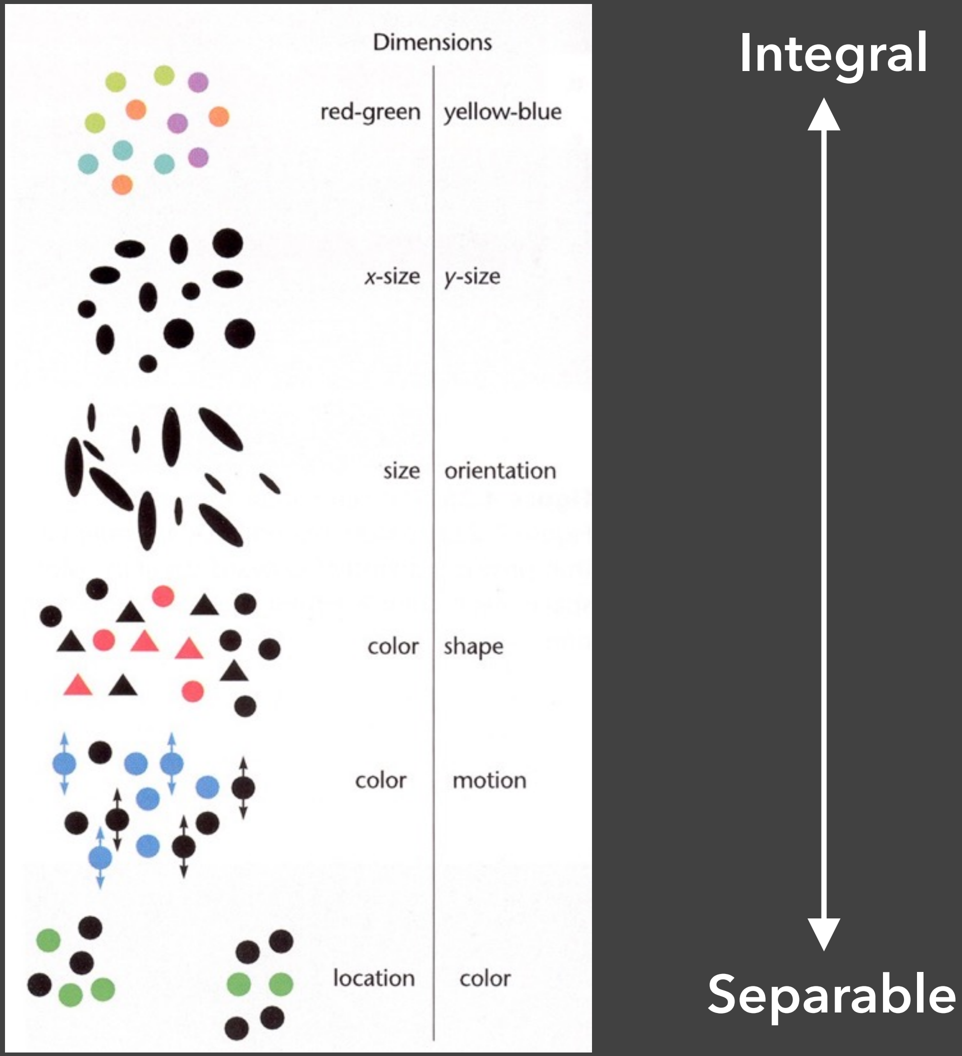
[MacEachren 95]

Angle & Angle

FIGURE 3.39. Bivariate map of NO_3 and SO_4 trends. The original Carr et al. version of this map used a wheel with eight spokes, rather than a simple dot, as the center of each glyph. When large enough, this added feature facilitates judgment of specific values. *After Carr et al. (1992, Fig. 7a, p. 234). Adapted by permission of the American Congress on Surveying and Mapping.*

[MacEachren 95]

Summary of Integral & Separable



[Figure 5.25,
Color Plate 10,
Ware 2000]

Set

Each card has **4 features**:

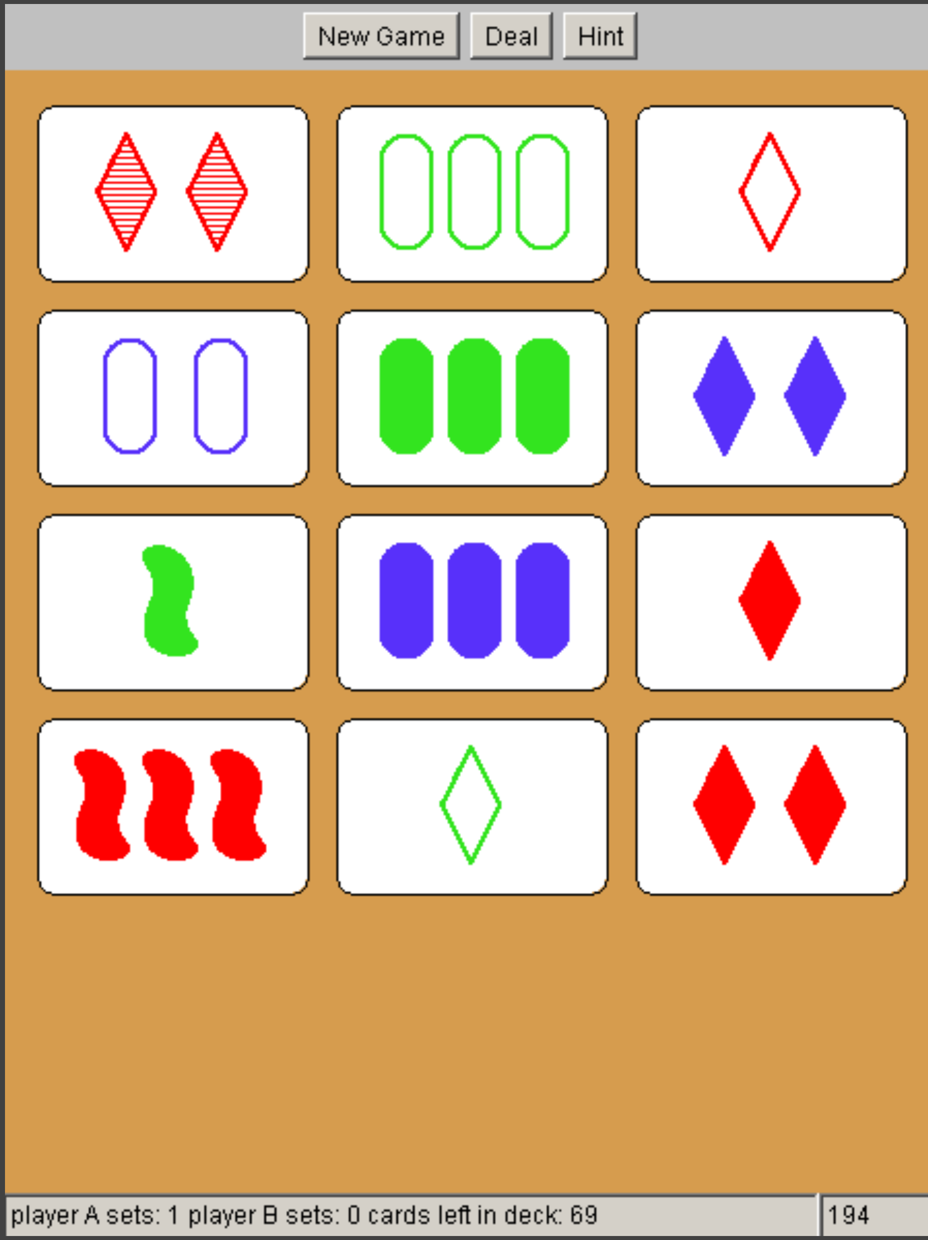
Color

Symbol

Number

Shading/Texture

A set consists of 3 cards in which each feature is the SAME or DIFFERENT on each card.



Gestalt Grouping

Gestalt Principles

Figure/Ground

Proximity

Similarity

Symmetry

Connectedness

Continuity

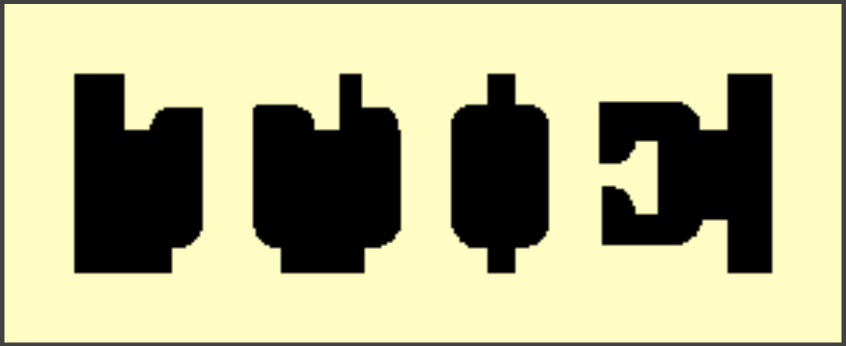
Closure

Common Fate

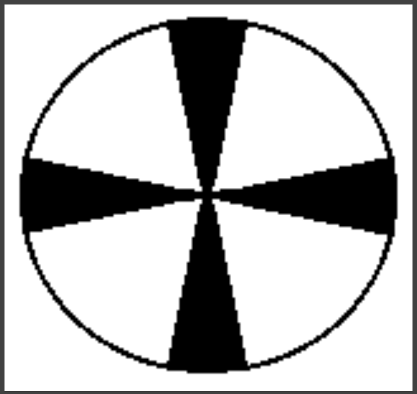
Transparency

Figure/Ground

Ambiguous



Principle of surroundedness

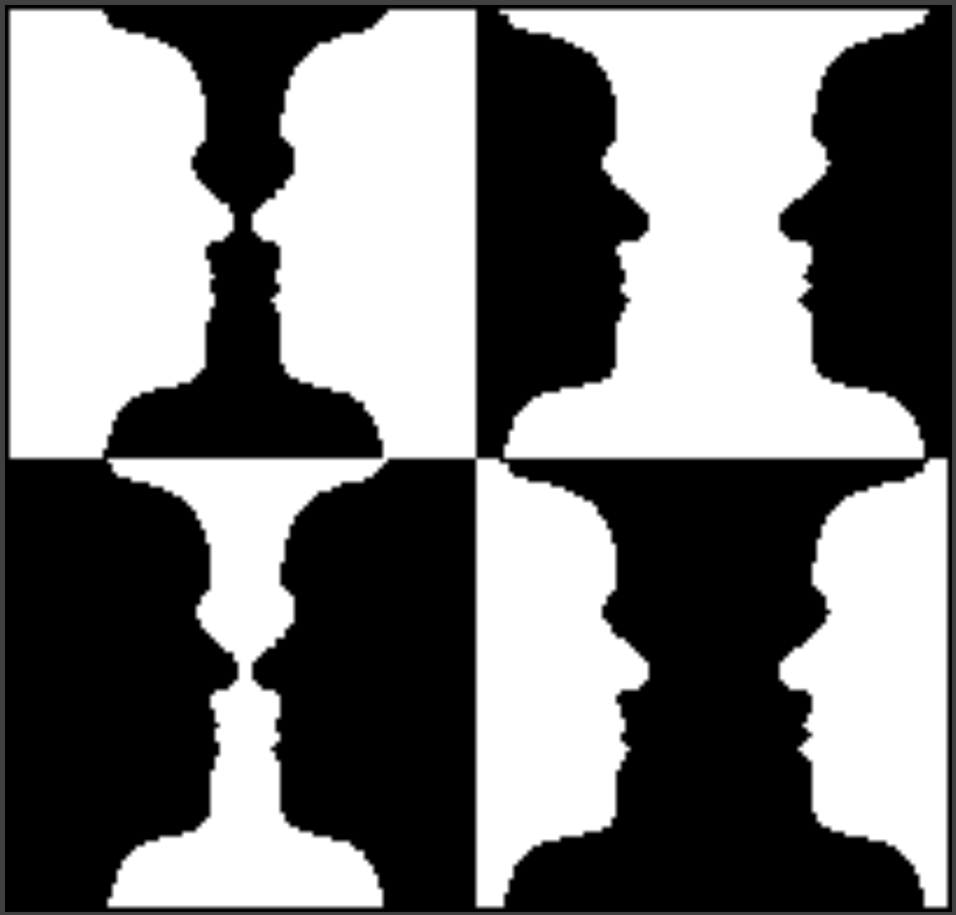


Principle of relative size

http://www.aber.ac.uk/media/Modules/MC10220/visper07.html

Figure/Ground

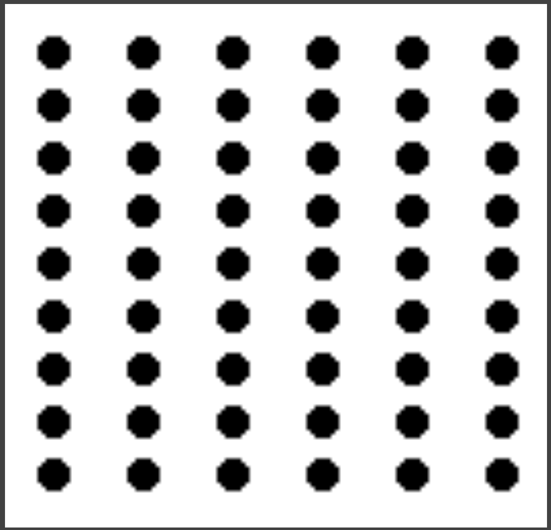
Ambiguous

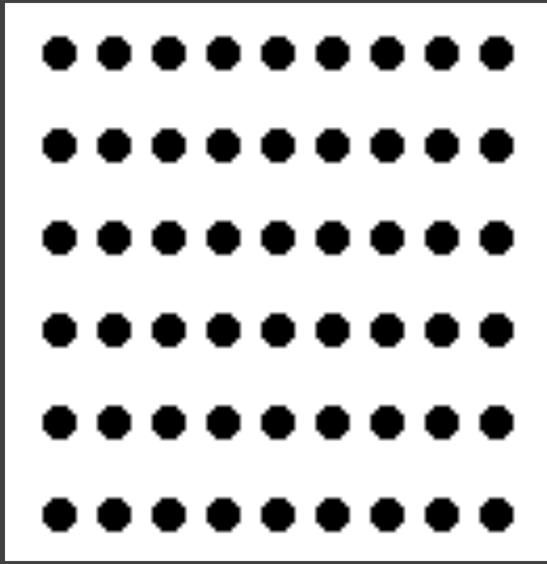


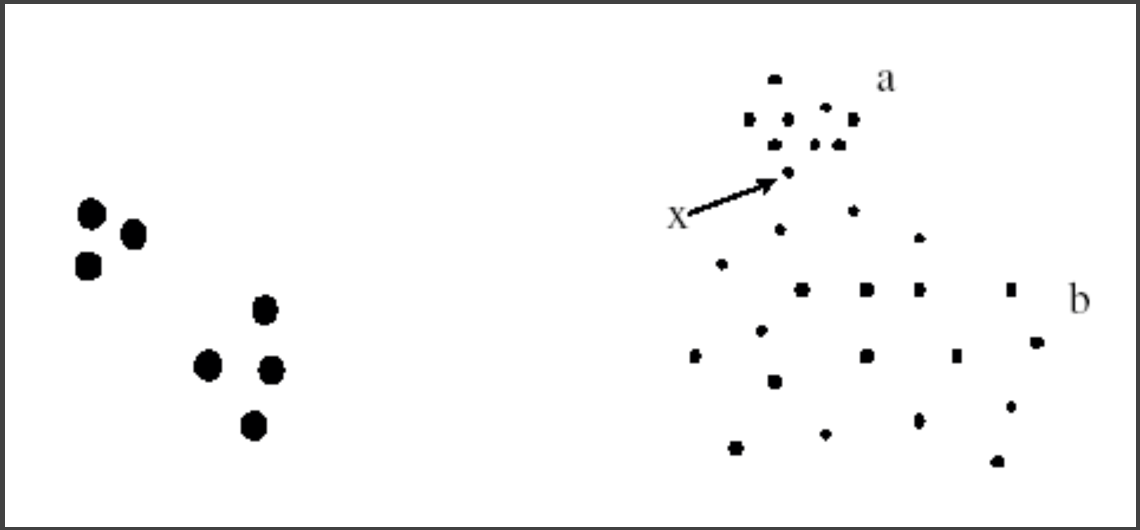
Unambiguous (?)

http://www.aber.ac.uk/media/Modules/MC10220/visper07.html

Proximity

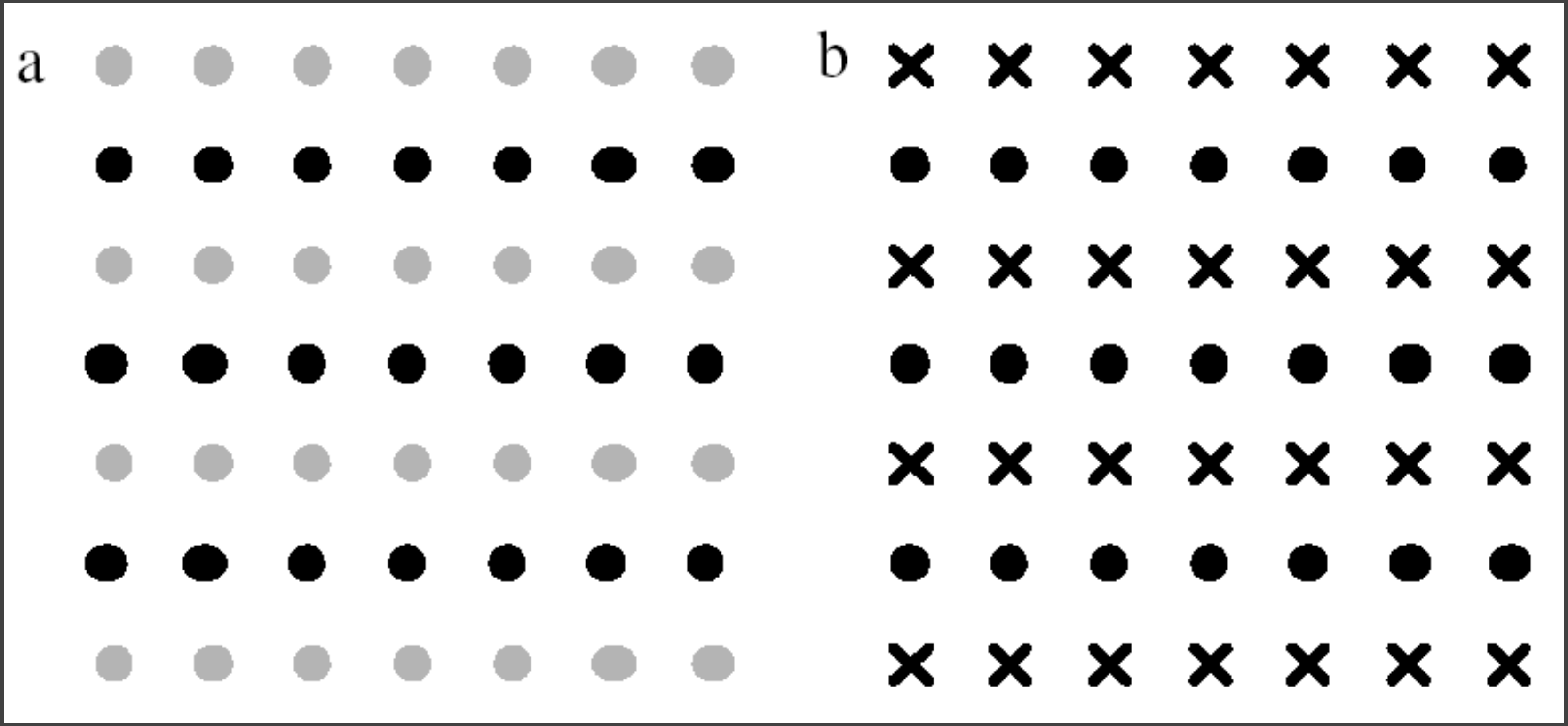






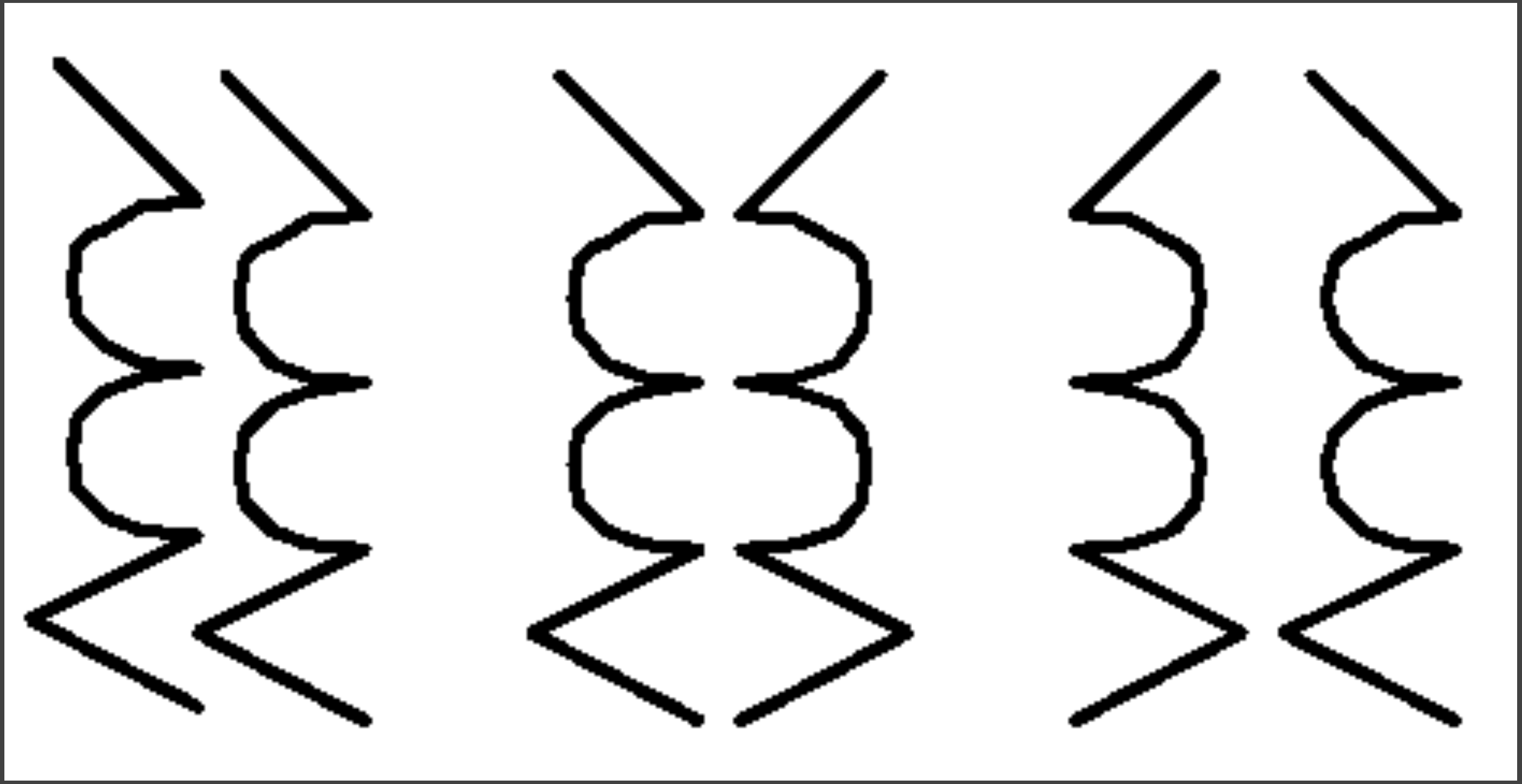
[Ware 00]

Similarity



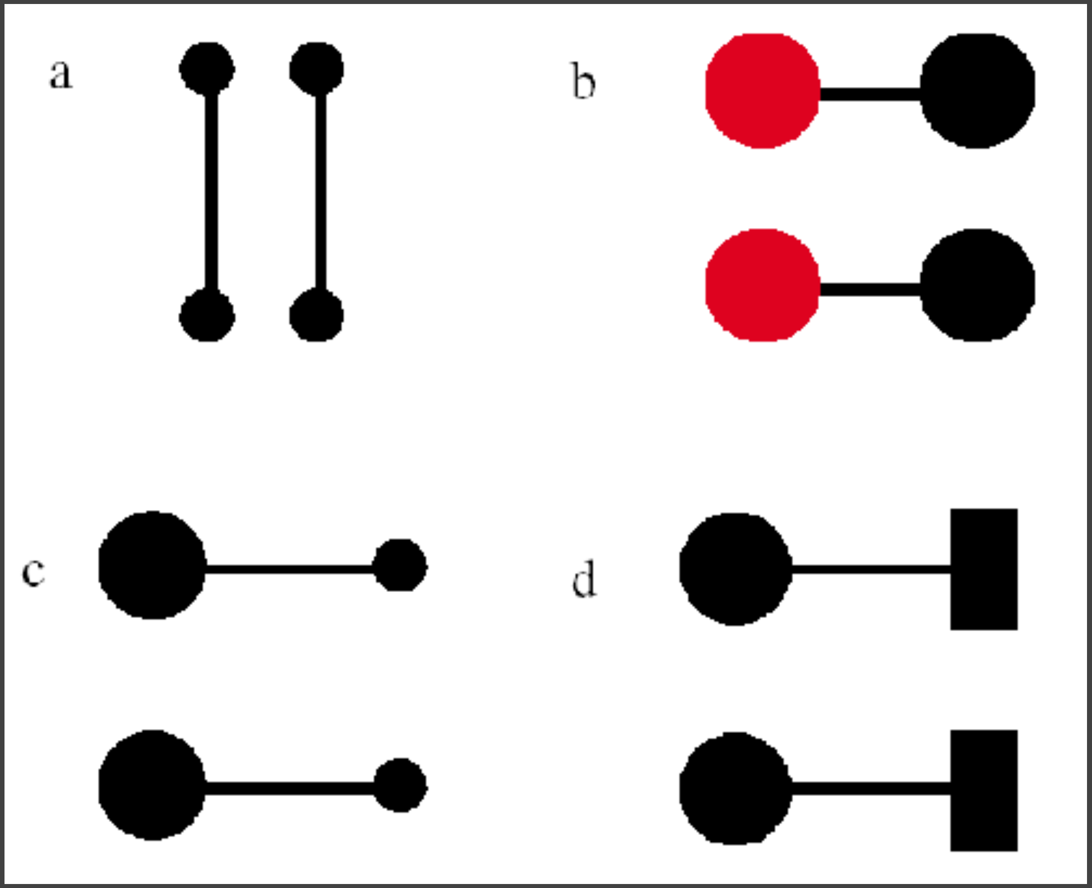
Rows dominate due to similarity [from Ware 04]

Symmetry



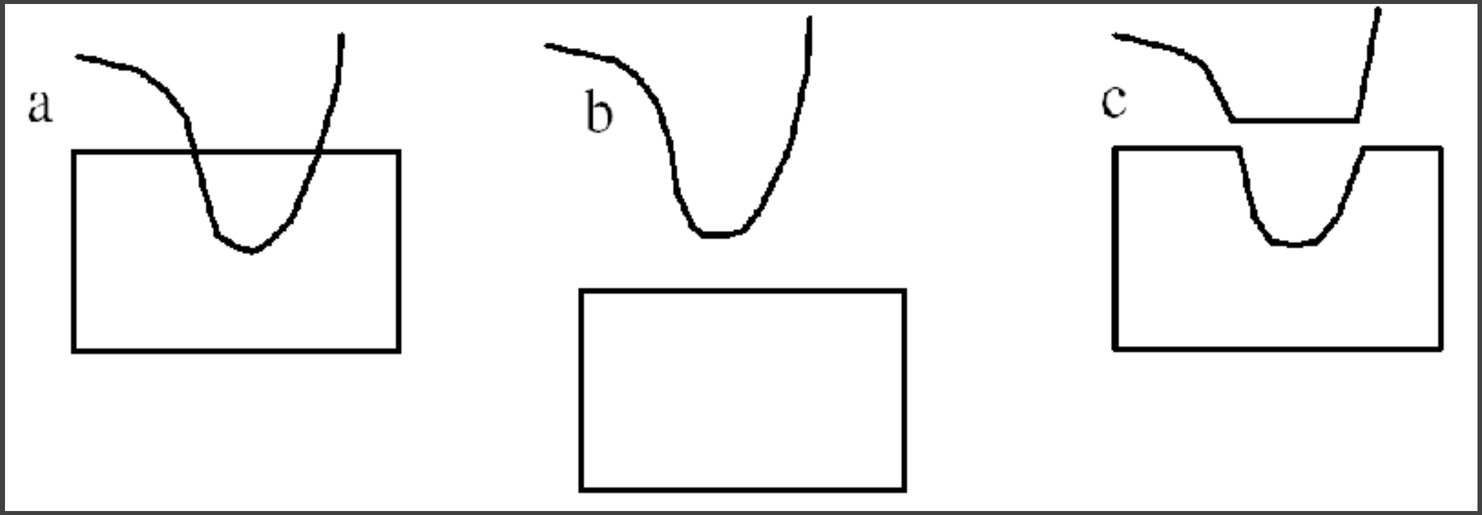
Bilateral symmetry gives strong sense of figure [from Ware 04]

Connectedness

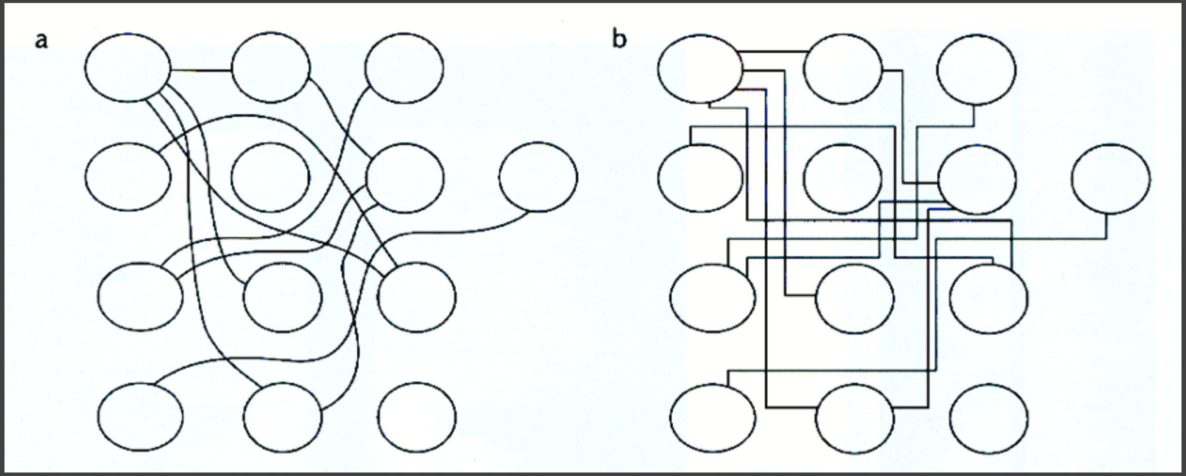


Connectedness overrules proximity, size, color shape [from Ware 04]

Continuity

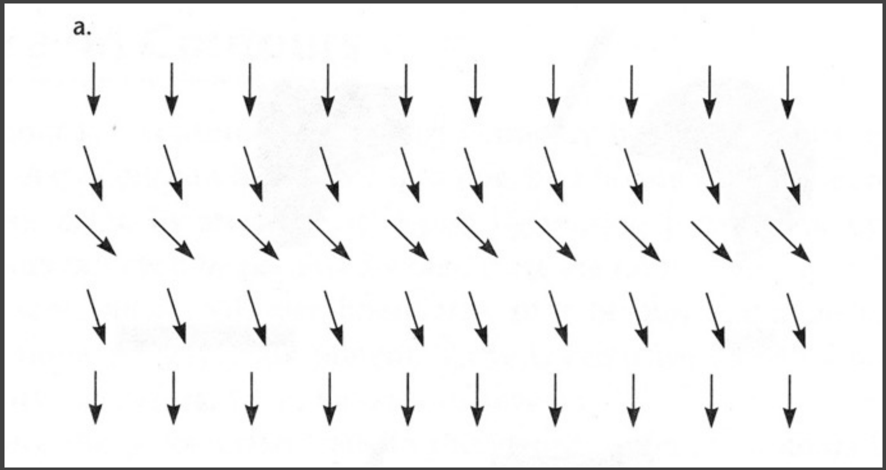


We prefer smooth not abrupt changes [from Ware 04]

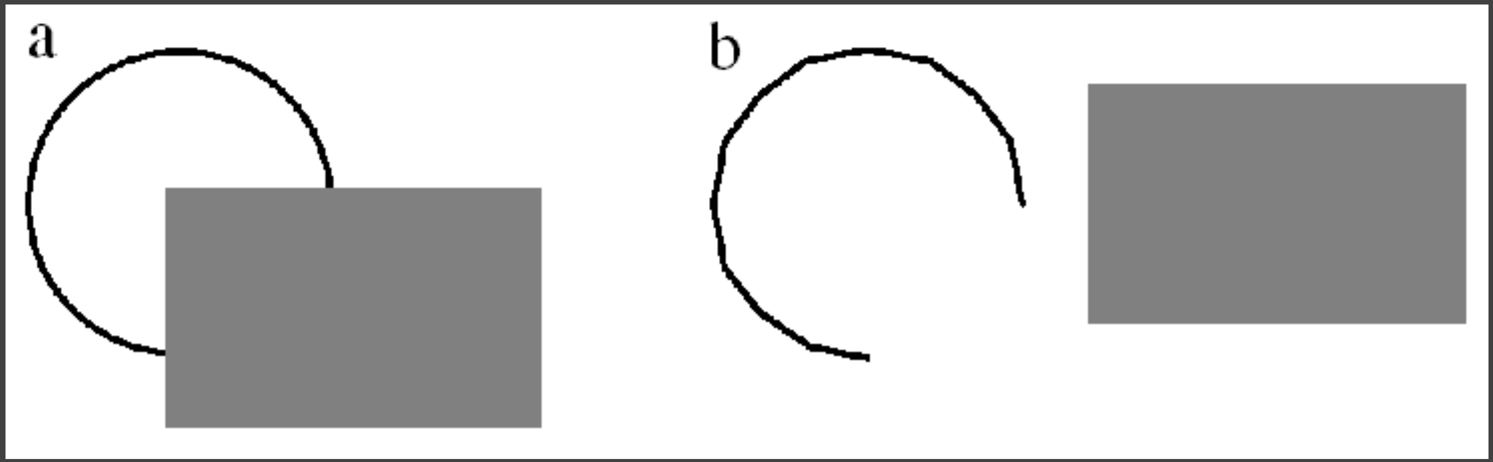


Connections are clearer with smooth contours [from Ware 04]

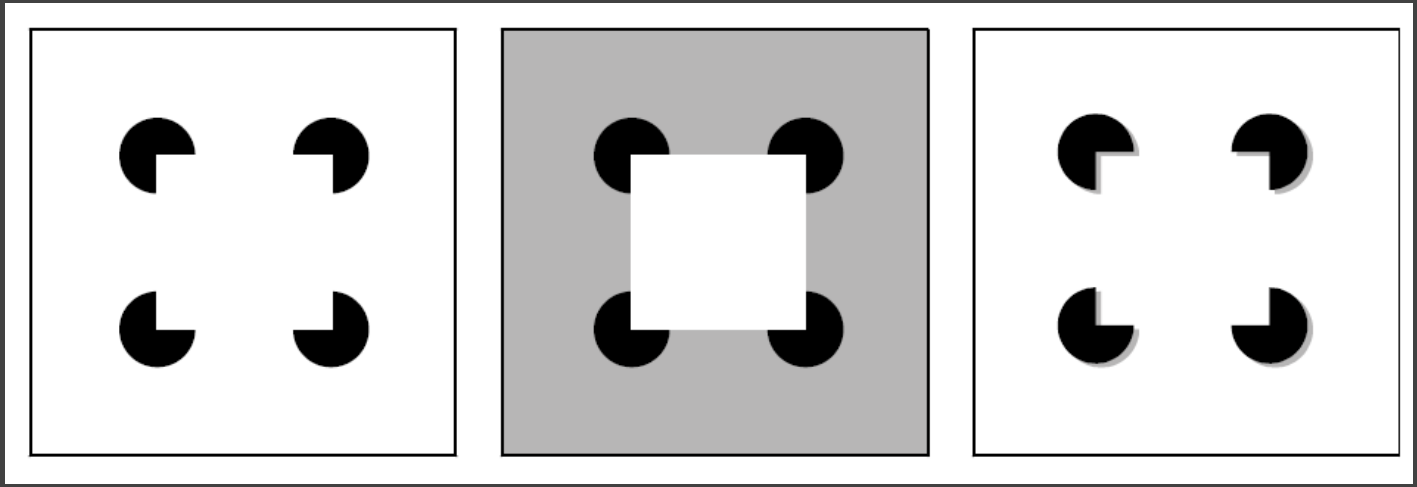
Continuity: Vector Fields



Closure

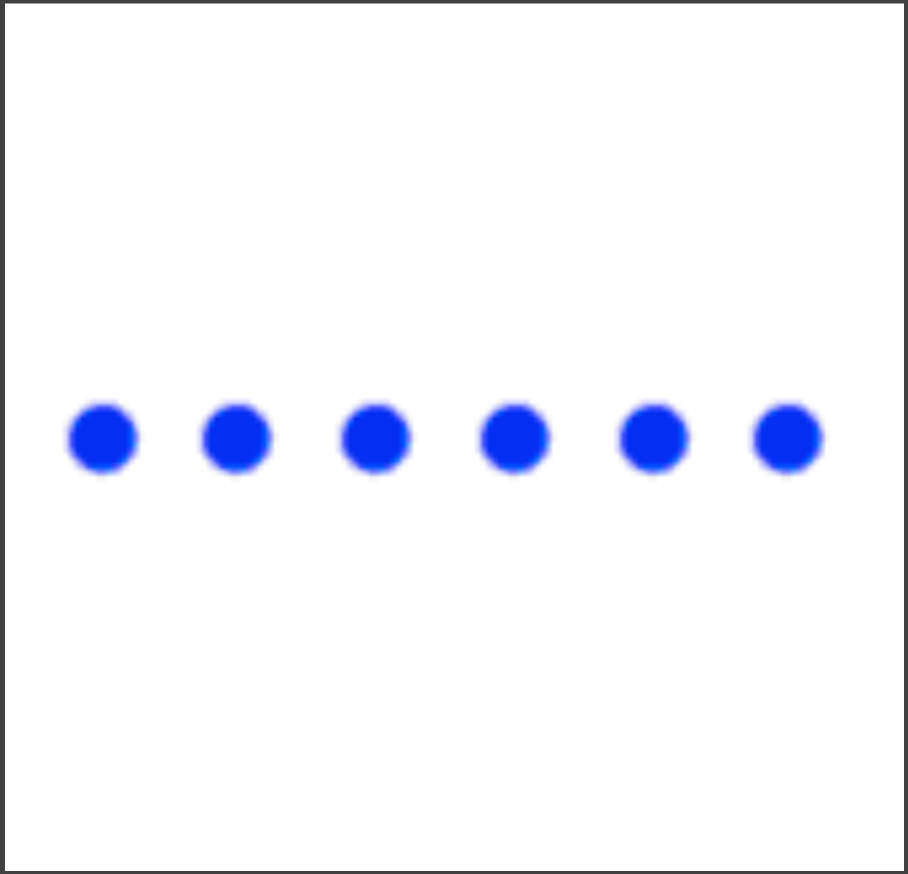


We see a circle behind a rectangle, not a broken circle [from Ware 04]



Illusory contours [from Durand 02]

Common Fate



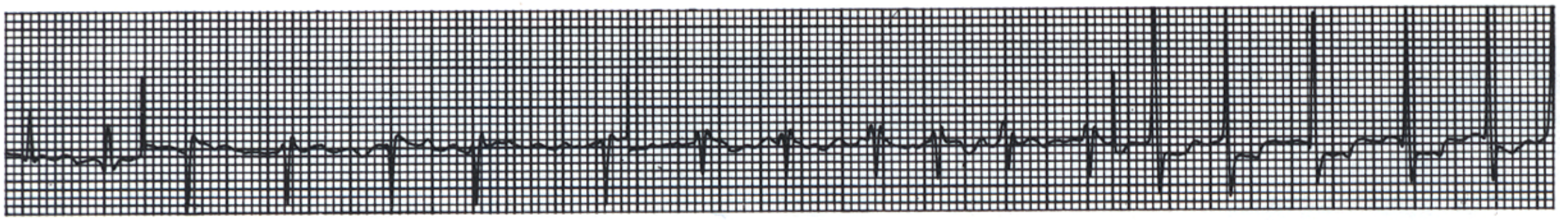
Dots moving together are grouped

Transparency

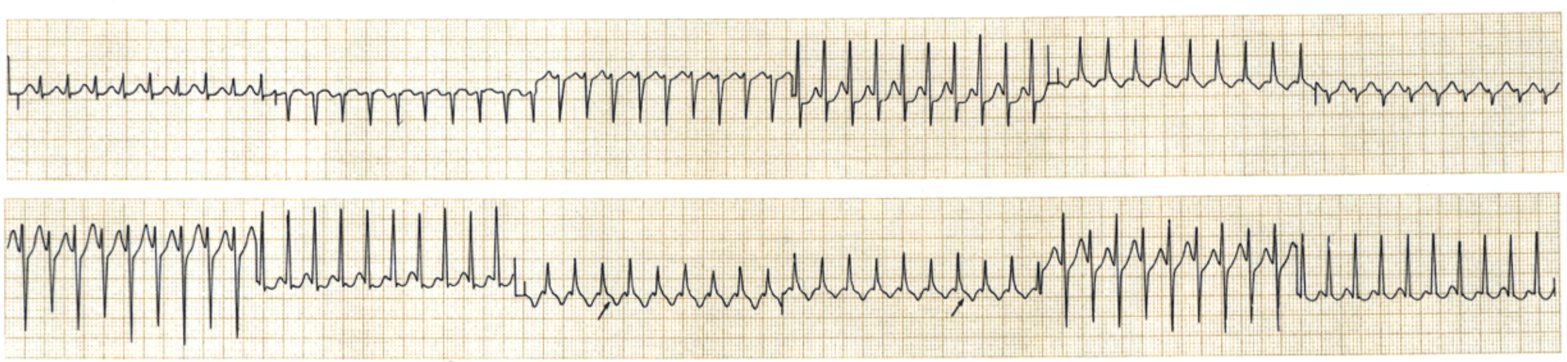
Requires continuity and proper color correspondence [from Ware 04]

Layering

Layering: Gridlines

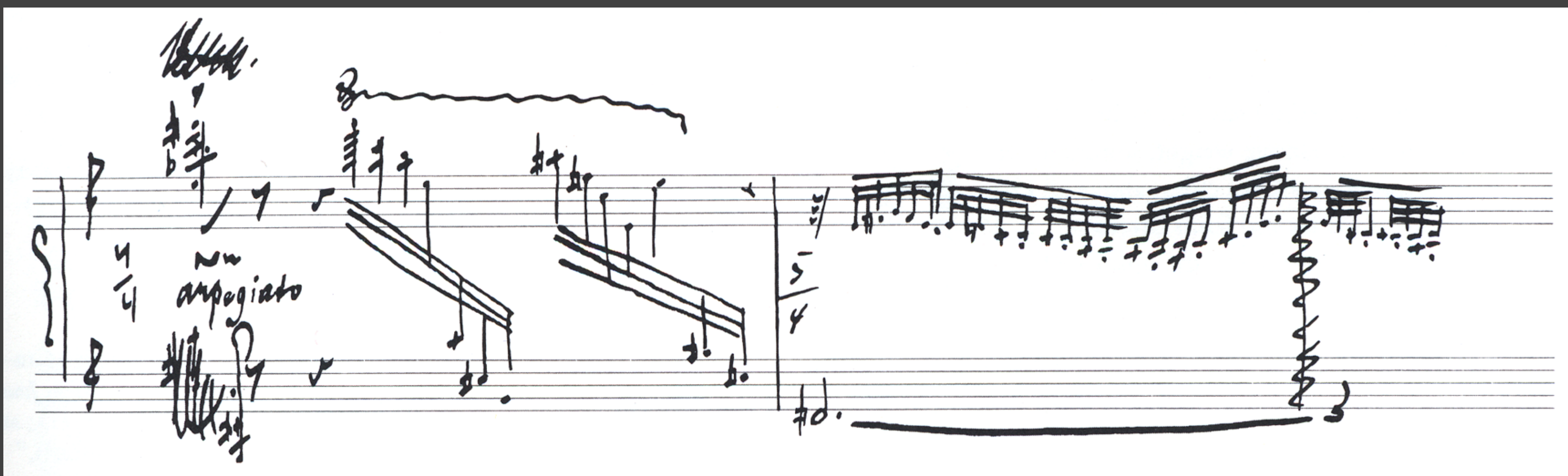


Signal and background compete above, as an electrocardiogram trace-line becomes caught up in a thick grid. Below, the screened-down grid stays behind traces from each of 12 monitoring leads:[4]



Electrocardiogram tracelines [from Tufte 90]

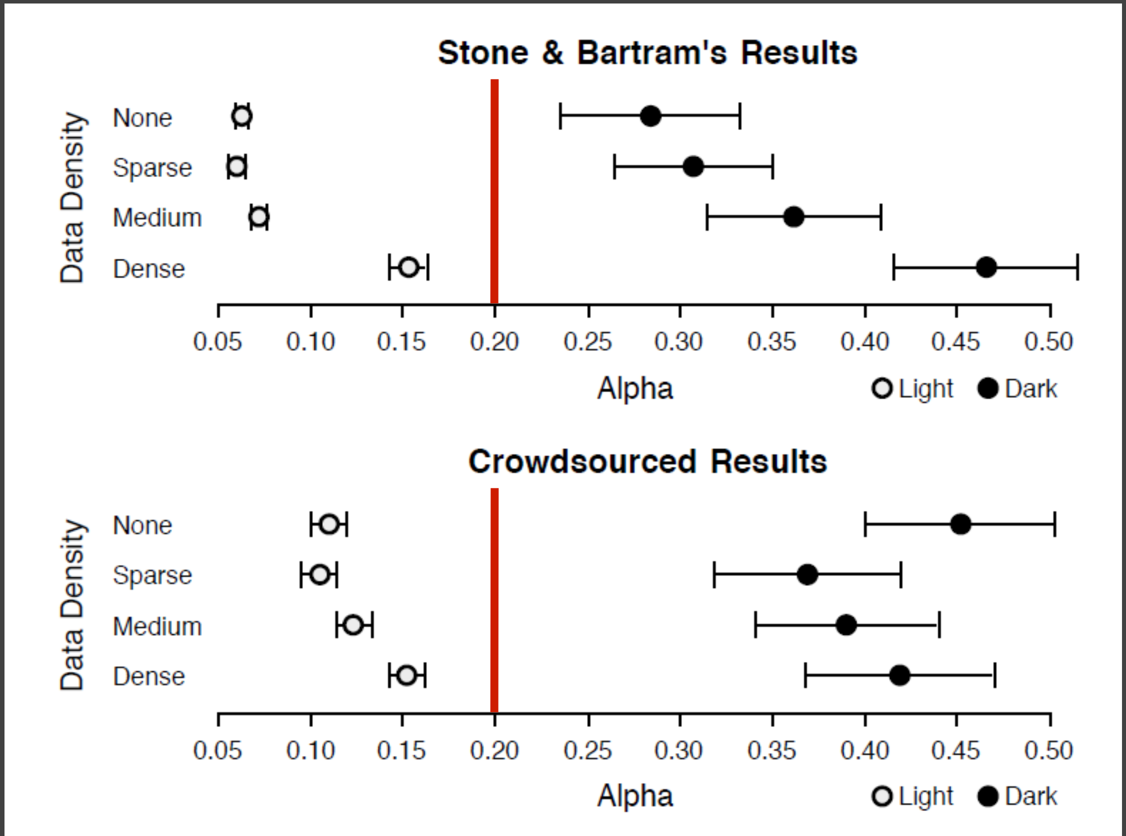
Layering: Gridlines



Stravinsky score [from Tufte 90]

Setting Gridline Contrast

How light can gridlines be and remain visible?
How dark can gridlines be and not distract?



Safe setting:
20% Alpha

[Stone & Bartram 2009]
[Heer & Bostock 2010]

Change Blindness

Change Blindness

Change Blindness

Change Blindness

Change Blindness

[Example from Palmer 99, originally due to Rock]

Demonstrations

http://www.psych.ubc.ca/~rensink/flicker/download/

http://www.youtube.com/watch?v=Ahg6qcgoay4

Summary

Choosing effective visual encodings requires knowledge of visual perception.

Visual features/attributes
Individual attributes often pre-attentive
Multiple attributes may be separable or integral

Gestalt principles provide high-level guidelines

We don't always see everything that is there!